Paleolimnological Investigation of Freshwater Lake Sediments in Insular Newfoundland

Part 1: Relationships Between Diatom Sub-fossils in Surface Sediments and Contemporary pH from Thirty-four Lakes

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PALEOLIMNOLOGICAL INVESTIGATION OF FRESHWATER LAKE SEDIMENTS IN INSULAR NEWFOUNDLAND

PART 1. RELATIONSHIPS BETWEEN DIATOM SUB-FOSSILS IN SURFACE SEDIMENTS AND CONTEMPORARY pH FROM THIRTY-FOUR LAKES

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ABSTRACT

Scruton, D. A. and J. K. Elner. 1986. Paleolimnological investigation of freshwater lake sediments in insular Newfoundland. Part 1: Relationships between diatom sub-fossils in surface sediments and contemporary pH from thirty-four lakes. Can. Tech. Rep. Fish. Aquat. Sci. 1521: iv + 50 p.

Thirty-four lakes in insular Newfoundland were sampled for fossil diatoms in surface sediments (top 1 cm) and contemporary water chemistry (pH) from August 14 to August 20, 1984. Lake pH ranged from 4.86 to 7.72, alkalinities from -40 to 1715 $\mu eq\ L^{-1}$ and lakes ranged from clear water to highly coloured systems (TCU values from 10 to 87.5). Fossil diatoms were identified, enumerated, and assigned to pH tolerance categories. The proportional distribution of diatom pH tolerance categories were used to calculate two widely applied indices, Index alpha (α) and Index B. These indices (Log_{10}), regressed with contemporary pH, yielded highly significant ($P < 0.001$) correlations that were used as region-specific transfer functions for calculation of inferential pH. Transfer functions for insular Newfoundland lakes compared favourably with those developed from other regional data sets.

RÉSUMÉ

Scruton, D. A. and J. K. Elner. 1986. Paleolimnological investigation of freshwater lake sediments in insular Newfoundland. Part 1: Relationships between diatom sub-fossils in surface sediments and contemporary pH from thirty-four lakes. Can. Tech. Rep. Fish. Aquat. Sci. 1521: iv + 50 p.

Du 14 au 20 août 1984, on a recueilli dans 34 lacs de Terre-Neuve des échantillons de sédiments superficiels (couche supérieure de 1 cm) afin de déterminer la présence de diatomées fossiles et des échantillons d'eau pour une étude chimique (pH). Le pH et l'alcalinité variaient respectivement de 4,86 à 7,72 et de -40 à 1 715 $\mu eq\ L^{-1}$, tandis que la couleur de l'eau allait de claire à très sombre (valeur TCU: de 10 à 87,5). On a identifié et compté les diatomées fossiles pour ensuite les classer selon des catégories de tolérance au pH. La distribution proportionnelle de celles-ci a servi au calcul de deux indices largement appliqués, soit l'indice alpha (α) et l'indice B. Une régression de ces indices en fonction du pH actuel (Log_{10}) a généré des corrélations très significatives ($P < 0,001$) qui ont été utilisées comme fonctions de transfert particulières à chaque région pour le calcul du pH fondé sur certaines déductions. Ces fonctions de transfert élaborées pour les lacs de Terre-Neuve soutiennent la comparaison avec celles mises au point à l'aide de séries de données provenant d'autres régions.

INTRODUCTION

The acidification of freshwater lakes and concurrent perturbation of resident biota in response to the deposition of acidic precipitation is now a well documented global phenomenon. Widespread acidification damage has been reported from Scandinavia, mostly in southern Norway and Sweden (Almer et al. 1974; Overrein et al. 1980). Acidification of aquatic and terrestrial ecosystems in other regions of Northern Europe, including the United Kingdom (Wells et al. 1985), Finland (Anonymous 1982) and West Germany (Kraus et al. 1985) have subsequently been reported. In North America, lake acidification was first documented in the LaCloche Mountains in Ontario (Beamish and Harvey 1972) and the Adirondack Mountains in the northeastern U.S.A. (Schofield 1976). Lake acidification in northeastern North America is now recognized as a widespread problem (Harvey et al. 1981; Bangay and Riordan 1983; Environmental Protection Association 1983).

In Atlantic Canada, Watt et al. (1979) first reported pH declines in 16 lakes in the Halifax region over a 21-year period from 1955 to 1976. Watt et al. (1983) subsequently reported on the acidification of seven Atlantic salmon rivers in southeastern Nova Scotia with concurrent extinction of Atlantic salmon populations. Other salmon rivers in the region are considered similiarly threatened. Underwood and Josselyn (1980), however, have suggested that natural organic acidity and proximity to local emission sources may be the primary causes of lake acidification in Nova Scotia.

In insular Newfoundland, recent lake surveys have confirmed the extreme susceptibility of the island's freshwaters to anthropogenic acidification but at present there is no evidence of widespread acidification damage (Scruton 1983, 1986; Clair 1981). Most sensitive freshwaters are demonstrating considerable alkalinity depletion but the most acidic systems (pH <5.0) appear to be weak organic acid dominated. Due to the preponderance of organic acid dominated systems, it has been difficult to determine the contribution of atmospheric deposition of strong acids (NO_3^- and SO_4^{2-}) to the acid-base chemistry of the region's lakes. In addition, the absence of any historical water chemistry for sensitive, low order lakes precludes any comparison through time as evidence of progressing acidification.

The fossil record from freshwater lake sediments has become an increasingly valuable tool to assess the possible effects of the deposition of atmospheric pollutants on dilute, acid-sensitive lakes (Merilainen 1967; Davis and Berge 1980; Del Prete and Schofield 1981; Charles 1984; Renberg and Hellberg 1982; Flower and Battarbee 1983; Delorme et al. 1984; Dickman et al. 1984). Although a variety of paleolimnological techniques have been investigated (Battarbee 1984a and b), a method using the relationship between preserved diatom assemblages in recently deposited sediment and contemporary lake pH has been most widely used to develop pH histories (Brakke 1984; Davis and Anderson 1985). Diatoms are unicellular algae with silicous cellwalls that are well preserved in lake sediments. Diatoms are sensitive indicators of water pH with each taxa being largely restricted to, or showing a strong preference for, a particular range of pH (Hustedt 1937-39). Contemporary relationships between diatoms (in water or surface sediments) and water characteristics can be quantified and used to interpret present and past aquatic environments (Battarbee 1979).

There are, at present, two distinct methods for relating diatom sub-fossil data to pH. The first method uses diatom floristic data to determine a quantitative index, the $\log_{10}$ transformation of which is related to pH by linear regression (Nygaard 1956; Renberg and Hellberg 1982). In the second method, a direct relationship is established between the diatom assemblage data and lake pH by means of multiple regression analysis, generating axis 1 of a principal components analysis, or through related ordination techniques (Davis et al. 1980; Davis and Berge 1980; Charles 1985; Davis and Anderson 1985). Once these calibration equations, or transfer functions, have been calculated it is possible to infer historical pH of lakes by applying these equations to diatom remains deeper in the sediments (Davis and Berge 1980; Renberg and Hellberg 1982). Deeper sediments in the lakes can be dated by ^{210}Pb, ^{137}Cs, pollen (largely by Ambrosia sp), and charcoal analysis to put a time scale on pH changes and onset of acidification (Davis et al. 1983; Charles and Whitehead 1985).

This inferential approach to assessing pH histories of lakes in relation to acid deposition is particularly valuable where there are no historical records of lake water chemistry (particularly pH) or where historical data is suspect due to differences in measurement, season of measurement, frequency of sampling, etc. Paleolimnological reconstruction uses a single technique to provide a continuous pH record over a long time frame (hundreds to thousands of years). Additionally, these techniques avoid the influence of seasonal variation in pH and other parameters by the integration of a range of seasonal conditions into a single sediment strata (be it surface sediment or downcore) frequently representing one or many years (Davis and Anderson 1985).

STUDY OBJECTIVES AND APPROACH

The primary objective of this study is to use a paleolimnological approach to the reconstruction of recent lake pH histories (over the last 100 years) to aid in understanding of the current status of insular Newfoundland's freshwater lakes in relation to the phenomenon of atmospheric deposition of strong acids. This study is intended to increase our understanding with respect to the onset, timing, rate, and magnitude of lake acidification, if it is in fact occurring, in our region. Data from insular Newfoundland lakes can then be integrated with data from other regions to evaluate interregional patterns in the response of lakes to atmospheric deposition. Additionally, it is hoped that this study will contribute to our knowledge of the acidification process in naturally acidic, brown water lakes by anthropogenic acid deposition, considering the recent paleolimnological evidence for conversion from weak organic acid dominated to strong mineral acid dominated lakes in the high deposition region of southern Norway (Davis et al. 1985).

A paleolimnological approach to acidification study was chosen for use in Newfoundland because of:

- the widespread (global) use of the techniques;
- the widespread acceptance of the reliability of the techniques in the elucidation of lake acidification;

- absence of historical pH data for insular Newfoundland lakes;

- problems associated with understanding the process of lake acidification in dystrophic or weak organic acid dominated systems (an abundant lake type in insular Newfoundland);

- endorsement of the scientific validity of this approach by the Royal Society of Canada (Hare 1984) and suggestion that paleo-research be included in future Federal Government study programs.

Paleoecological investigation of insular Newfoundland lakes has been developed as a 3-year study program, starting in April 1984 and planned for continuation to March 1987. The following are the principal phases in the study plan and the associated time frames:

Year		
1984-85	Phase I	- Relationships between diatom sub-fossils and contemporary lake pH in surface sediments from 34 lakes.
	Phase II	- Downcore diatom stratigraphy and inferred pH history for 7 lakes. - Major ion and metal determinations in surface sediments and downcore strata.
1985-86	Phase III	- Refinement of transfer functions and pH histories from data collected in 1984 by subdivision of diatom taxa, reassignment of pH tolerance category, and principal components analysis of surface sediment data.
1986-87	Phase IV	- Downcore collection from two (or more) lakes with high sedimentation rates, refined sectioning of strata, and use of calibrated transfer function(s) (from Phase III above) to precisely describe the onset, timing, rate and magnitude of pH change.

Due to the time frame involved in this research program it has been decided to publish the data arising from the study as a report series. The first two reports in this series are entitled Part 1: Relationships between Diatom Sub-Fossils in Surface Sediments and Contemporary pH from Thirty-Four Lakes, and Part 2: Downcore Diatom Stratigraphies and Historical pH Profiles for Seven Lakes. The third report in the series will deal with spatial and temporal (inferred historical) variation in major ions and heavy metals in lake sediments, particularly with respect to evidence for atmospheric deposition of these elements or increased mobilization from the watershed. Subsequent publication of the information obtained in Phases III and IV of this study will be published as a continuation of the report series and/or as summary publications in the primary literature.

MATERIALS AND METHODS

LAKE SELECTION

Lakes considered for paleolimnological study were selected from an extensive lake inventory data base for the island which included a province-wide survey of 109 headwater lakes conducted in 1981 (Scruton 1983) and a follow-up survey of 90 lakes on the south coast of the island conducted in 1983 (Scruton and Taylor 1986). In order to limit the geographic scope of this program, all study lakes were located along the south coast of the island and on the Northern Peninsula (Fig. 1). In the initial phase of this study, intended to establish a regional relationship between sub-fossil diatoms and contemporary water chemistry (pH), lakes were selected to represent the full range of limnological conditions, in particular the full range of pH, identified for insular Newfoundland lakes (Scruton 1985). Selected morphometric, chemical and physical parameters for the study lakes are listed in Tables 1 and 2.

Additional criteria used to determine a lake's suitability for study included:

- Lake watersheds were located in remote areas removed from human disturbance (in particular logging or other forest harvesting operations).
- Lakes were selected in regions where the influence of forest fires and insect infestation is likely to be minimal (i.e. study areas were largely characterized as having limited forest development).
- Most lakes selected were headwater, or low order, systems with simple morphometry and hydrology.
- Lakes were in the size range of 10-1000 ha (with three exceptions).
- Lake watershed area to surface area ratios were low, all less than 25:1.
- Lakes selected for study also included shallow water bodies, many of which are characterized as dystrophic.

SAMPLE COLLECTION

Sediment cores were collected from the 34 study lakes from August 14 to 20, 1984. All lakes were accessed by Bell Jet Ranger 206B helicopter and all coring operations were conducted from the floats of this aircraft. Coring sites were established over the point of apparent maximum depth (mid-lake) and the depth of the site was recorded. Cores were collected using a 10-cm diameter, light-weight Williams and Pashley (1979) corer, designed for use in unconsolidated deposits. One core per lake was obtained and all cores retained for analysis had an undisrupted sediment/water interface. Cores were extruded and sectioned immediately at the lake side so as to minimize disturbance of the highly flocculent sediment. An extrusion device was employed which used hydraulic water pressure to upwardly (vertically) extrude the core. A collar on the extrusion

device shaved off the outer 1-cm diameter of core, so as to remove any sediment that may have experienced smearing along the inside of the core tube. The top 1-cm horizon was removed from the core by spoon (in very watery sediment) or by spatula (in more-consolidated sediment). The horizon was transferred to pre-labelled "whirl-pak" bags and frozen upon return to the field laboratory.

WATER ANALYSIS

Water samples were collected by surface dip about 1 m below the lake surface at the time of core collection, and were subsequently shipped to a laboratory for analysis. The samples were analyzed for the following parameters:

pH	Sulphate
Alkalinity	Chloride
Dissolved Organic Carbon	Orthophosphate as P
Colour	Nitrate as N
Turbidity	Aluminum
Calcium	Iron
Magnesium	Manganese
Sodium	Total hardness (calculation)
Potassium	Bicarbonate (calculation)

All methods followed those described by Environment Canada (1979) and the American Public Health Association et al. (1975). For details on analytical procedures and detection limits refer to Scruton (1983). pH and total inflection point (or Gran) alkalinity were also determined at a field laboratory within 24 hours of sample collection.

Non-marine (or excess) concentrations of calcium, magnesium, sodium, potassium, and sulphate were calculated after equations in Thompson (1982). Organic anions (as $\mu eq\ L^{-1}$) were calculated from pH and dissolved organic carbon (DOC) after Oliver et al. (1983).

An ion balance, as percent difference, was computed from the sum of cations (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, H^{+}, Al, Fe, Mn) and the sum of anions (Cl^{-}, SO_4^{-2}, alkalinity, organic anions) after the following equation (Environment Canada 1979):

$$\text{Percent Difference} = \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \times 100 \qquad (1)$$

The percent difference ranged from 0.04 to 8.06, which is considered very acceptable for insular Newfoundland's highly dilute, often highly colored, freshwaters.

LABORATORY PREPARATION OF SEDIMENT

Each sediment sample was thawed and mixed thoroughly prior to being divided into three aliquots for the required analyses. One aliquot was reserved for diatom identification and counts, a second for chemical analyses, and a third for determination of wet/dry weights and for dating by ^{210}Pb analysis (downcores only). It was essential to achieve all analyses from samples from a single core, as matching one core to another from the same lake is a complex and often unreliable procedure (Elner and Happey-Wood 1980; Dearing et al. 1981).

SEDIMENT DIGESTION AND SLIDE PREPARATION

Diatoms were cleaned by an acid digestion technique. Small aliquots of sediment (0.5 ml) were heated to boiling in a 5:1 mixture of concentrated $H_2SO_4.HNO_3$ acid until digestion was visibly complete, usually within an hour. Cleaned samples were cooled and centrifuged in an IEC B-20A centrifuge at 3,000 rpm (1,500 g) for 2 minutes. The supernatant was discarded and the diatom pellet cleaned in deionized water. These washing procedures were repeated a total of five times. The diatom suspension was diluted with deionized water prior to slide preparation. Diatom suspensions were mounted in "Hyrax" on slides and ringed for permanence.

DIATOM IDENTIFICATION AND COUNTING

Diatom identification was based in the most part on the floras of Cleve-Euler (1951-1955), Hustedt (1930), Molder and Tynni (1967-1973), Patrick and Reimer (1966, 1975) and Tynni (1975-1981) and also included Renberg (1977). Taxa were assigned to pH tolerance groups based on the Hustedt (1937-1939) classification as follows:

1) Alkalibiontic (Alkb); occurring at pH values >7;

2) Alkaliphilous (Alk); occurring at pH about 7 with widest distribution at pH 7.7;

3) Indifferent or Circumneutral (C); equal occurrences on both side of pH 7;

4) Acidophilous (Ac); occurring at about pH 7 with widest distribution at pH <7;

5) Acidobiontic (Ab); occurring at pH values <7, optimum distribution at pH 5.5 and under.

The term "indifferent" can be misconstrued in an ecological sense so the less ambiguous term "circumneutral," adopted by Battarbee (1984a), has been used in this study. The number of frustules counted from each surface sediment sample is contained in Table 1.

DATA ANALYSIS

Index alpha (α) and Index B were calculated from the diatom floristic counts of the 34 surface sediment samples. Index alpha (α) after Nygaard (1956) was calculated from the following equation:

$$\text{Index alpha} = \frac{\text{acid units}}{\text{alkaline units}} \qquad (2)$$

where acid units = % acidophilic taxa + 5(% acidobiontic taxa)
alkaline units = % alkaliphilic taxa + 5(% alkalibiontic taxa)

The acid units were calculated by adding the relative frequency of the acidibiontic species, multiplied by five, to the relative frequency of the acidophilous taxa. The alkaline units were calculated in the same manner. The relative frequencies of the acidibiontic and alkalibiontic species were multiplied by five to emphasize that they are extreme groups (Nygaard 1956).

Index B, after Renberg and Hellberg (1972), was calculated from the following equation:

$$\text{Index B} = \frac{\%C + 5 \times \%\,Ac + 40 \times \%\,Ab}{\%C + 3.5 \times \%\,Alk + 108 \times \%\,Alkb} \qquad (3)$$

where C, Ac, Ab, Alk, and Alkb correspond to pH tolerance groups of Hustedt (1937-39).

All regression analyses were completed using the Statistical Package for the Social Sciences (Nie et al. 1975). Both simple linear regressions (SR) and geometric mean regressions (GMR) (after Ricker 1975, 1984) were computed. The significance of regression coefficients (r) was determined by Student's "t" test. Cluster analysis of the diatom frequency data (only the taxa identified in Fig. 4) was completed using Biomedical Computer Programs (Dixon and Brown 1979). The distance matrix (amalgamation distance) in the cluster analysis was based on a chi-square statistic.

RESULTS

Lakes selected for paleolimnological study represented a wide range of limnological characteristics identified for insular Newfoundland lakes (Scruton 1985). Lake surface areas ranged from 6 to 1117 ha, with one lake less than 10 ha, 20 lakes from 10 to 100 ha, and 11 lakes from 100 to 300 ha (Table 1). Only one lake in the excess of 1000 ha was included in the sample. Previous survey efforts have largely focused on smaller lakes, mostly less than 1000 ha, as larger, high order lakes had been excluded due to their hydrological nature and related low sensitivity to acidification. Watershed area to lake surface area ratios were low, ranging from 2.3 to 12.9 (Table 1), which is characteristic of headwater systems and well within the suggested upper limit of 25:1 as recommended by the PIRLA (Paleolimnological Investigation of Recent Lake Acidification) Project (Charles and Whitehead 1985). Twenty-seven lakes were headwater (first order) systems, while the sample also included five second-order

lakes, one third-order lake and one fifth-order system (Table 1). Drainage patterns were therefore simple, in most cases involving one or two lakes and their respective watersheds.

Lake elevations ranged from 30.5 to 480.1 m (Table 1). Three lakes with elevations of less than 100 m were located on the Strait of Belle Isle lowlands (Damman 1983) on the Northern Peninsula. This ecoregion is characterized by elevations of 60 m or less. Higher elevation lakes (250-500 m) were located in the Long Range Mountains, on the Northern Peninsula and along the southwestern coast of Newfoundland. The remainder of the lakes were located along the south coast from about 59°W longitude to about 54°30'W longitude, at more moderate elevations (100-300 m).

Maximum lake depths were approximated by sounding during coring of each lake. Sample location for core collection was established over the apparent deepest point in the lake, established visually based on surrounding topography. Actual maximum depth was not confirmed by means of a bathymetric survey. Apparent maximum depth for the study lakes ranged from 1.0 to 23.0 m, with 16 lakes demonstrating a maximum depth of less than 5.0 m (Table 1). For lakes #219, 642, and 653 bathymetric maps were available and, in all cases, sample depth was less than the maximum depth determined by bathymetry.

Lakes selected for survey also represented the range of chemical conditions identified for insular Newfoundland lakes. Lake pH varied from 4.86 to 7.72 representing lake types from small, shallow lakes with considerable natural organic acidity to highly mineralized lakes underlain by limestones and dolomites (Table 2). Alkalinity values ranged from -40 to 1715 $\mu eq\ L^{-1}$, with 29 lakes being characterized by extremely low alkalinities of less than 100 $\mu eq\ L^{-1}$ (Table 2). Most dilute lakes demonstrated a deficit in alkalinity as determined by [Excess calcium and Excess magnesium] minus Alkalinity, with this deficit ranging from 18 to 86 $\mu eq\ L^{-1}$. Lake water colour ranged from 10 to 87.5, with 13 lakes characterized as clear water (TCU of <15), 11 lakes classified as brown water systems (TCU of 16-50) and 11 lakes classified as being highly colored (TCU of >50) (Table 2). Dissolved organic carbon (DOC) varied from 1.6 to 12.9 $mg\ L^{-1}$, with 16 lakes (47%) with DOC values greater than 5.0 while organic anion equivalence ($COOH^-$) varied from 14.4 to 107.7 $\mu eq\ L^{-1}$ (Table 2). Colour, DOC, and $COOH^-$ provide an indication of the strong influence of natural organic acidity on the region's freshwaters, reflecting the abundance and wide distribution of peatlands and organic soils (Wells and Pollet 1983). The strong influence of the marine environment on freshwater chemistry was evidenced by the relatively high chloride (34-192 $\mu eq\ L^{-1}$) and sodium (39-174 $\mu eq\ L^{-1}$) values (Table 2) relative to dilute, continental freshwater lakes (Armstrong and Schindler 1971, Scruton 1984). Sodium was the dominant cation in 26 lakes, while calcium was dominant in 8 lakes. Lakes were dominated anionically by chloride in 21 lakes, bicarbonate in 7 lakes and by organic anions in 6 lakes. Sulphate values, as an indicator of anthropogenic pollution, were relatively low ranging from 13 to 75 $\mu eq\ L^{-1}$ (Table 2). Total aluminum ranged from 10 to 254 $\mu g\ L^{-1}$ (Table 2), with values in excess of 100 $\mu g\ L^{-1}$ associated, for the most part, with highly colored lakes, suggesting organic complexation with the metal.

Diatom valves were found to be well preserved in all sediments and a total of 207 diatom species, representing 35 genera, were identified from the 34

lakes. A list of these species, including precise taxonomic reference and assigned pH tolerance category, is contained in Appendix 1. The assignment of each taxa to pH tolerance category was made on the basis of the literature and not on the distribution of the species in the study lakes in relation to lake acidity.

The proportional distribution of acidobiontic, acidophilous, circumneutral, alkaliphilous, and alkalibiontic taxa found within the surface sediment series are presented in Fig. 2. Taxa with no assigned pH tolerance category (see Appendix 1) were classified as unknown. Unknown taxa comprised a relatively small proportion (<10%) of the total diatom count in each lake, with the exception of lake #670 where taxa of unknown pH tolerance represented 11% of the total. It is noteworthy that alkaliphilic taxa were present in all study lakes making it possible to develop a pH-log alpha (α) calibration equation from data for all 34 lakes. Alkalibiontic taxa were present in only two lakes (#2 and #253) and were a minor component of the diatom count. Acidophilic taxa were the dominant pH tolerance category in 26 lakes with pH's ranging from 4.82 to 6.10, while acidobiontic taxa were dominant in one lake (#641, pH of 4.94), circumneutral taxa dominant in three lakes (#s 1, 2 and 202; pH's of 7.72, 7.42 and 6.42, respectively) and alkaliphilic taxa were dominant in four lakes (#s 11, 21, 253 and 668; pH's of 7.26, 7.10, 7.45 and 6.48, respectively).

A cluster analysis of diatom frequency data (Fig. 3) shows clear separation of the lakes into four major categories according to both measured pH and Index B inferred pH. The lowest pH cluster, I, contains six lakes, all of which are within the measured pH range 4.9 to 5.2 and four of which were in the inferred pH range of 5.0 to 5.2. Lake # 678, with a measured pH of 5.2 and inferred pH of 5.8, does not separate well into this low pH cluster. From the floristic data presented in Fig. 4, it is evident that the diatom assemblages of Cluster I lakes are dominated by the acidobionts Actinella punctata Lewis, Semiorbis hemicyclus (Ehr.) Patr., Tabellaria quadriseptata Kunds and the acidophilous taxa Anomoeneis serians v. brachysira (Breb. Kutz.) Hust., Cyclotella glomerata Bachmann, Frustulia rhomboides (Ehr.) DeT.. Eunotia species belonging to either of these pH tolerance categories are also common in Cluster I. Cluster II is a large group of 18 lakes, 17 of which fell in the measured pH range 5.2 to 5.9 and the inferred pH range 5.2 to 5.9. Lake # 671 is the only outlier within this cluster with a measured pH (4.9) lower than the cluster norm, although the inferred pH (5.3) does conform to the pH range for the cluster group. The dominant taxa of cluster II are Anomoeneis serians v. brachysira, species of the genus Eunotia, Frustulia rhomboides, Melosira distans (Ehr.) Kutz., Tabellaria flocculosa and Cyclotella stelligera (Grun.) Cl.. The acidobionts found in Cluster I are also prevalent in Cluster II. Cluster II can be subdivided into two further groups of lakes, IIa and IIb (see Fig. 3). However, this division appears to be influenced by parameters other than pH. The third major Cluster, III, contains four lakes within the measured pH range 5.5 to 6.4 and the inferred pH range 5.8 to 6.6. Lake #215 does not separate well in this cluster, having a lower measured pH (5.5) and inferred pH (5.8), more comparable with lakes in Cluster II. Cluster III is characterized by the taxa Anomoeoneis serians v. brachysira, species of the genera Eunotia and Frustulia, Tabellaria flocculosa, Cyclotella stelligera and C. compta (Ehr.) Kutz.. Cluster IV comprises the six remaining lakes, which have a measured pH range between 6.4 and 7.7 and an inferred pH range from pH 6.9 to 7.9. The lakes in this last cluster contain a quite different floristic composition. The dominant taxa are all

indifferent or alkaliphilous including Achnanthes sp., Anomoeoneis vitrea (Brun.) Ross, Cyclotella compta and Fragilaria pinnata Ehr.. Other alkalibionts including Cyclotella iris Brun. are present in lakes of this cluster group. Thus, the four lake groups clustered from the diatom frequency data fit both the measured and inferred pH sequences rather closely. The relative frequencies of the most commonly occurring diatom taxa in the surface sediments are plotted against measured lake pH in Fig. 4.

Diatom floristic data, as proportional composition of pH tolerance groups, for the 34 surface sediment samples were used to calculate index alpha (α) (Nygaard, 1956) and Index B (Renberg and Hellberg, 1972). Values of the $\log_{10}$ transformation of each of these indices are regressed on contemporary lake water pH in Fig. 5 and 6. Both a simple regression (SR) and a geometric mean regression (GMR) were computed as the transfer functions derived for each index. The correlation coefficient of regression (r^2) was very highly significant for both scattergrams. However, the log Index B regressions produced the closer fit, as shown by higher r^2 values and lower standard errors, S_e (Table 3). More than twice the number of outliers are evident on the log index alpha (α) regressions (lakes #253, 202, 225, 671, 670, 12, 672, 225) (Fig. 5) as opposed to the log index B regressions (lakes #1, 653 and 669) (Fig. 6). In both cases the geometric mean regression of the $\log_{10}$ of the indices versus contemporary pH resulted in increasing the y-intercept, the slope and the standard error (S_e), as compared to the simple linear regressions.

The floristic data for the 34 surface sediment samples was used to calculate past pH values (inferred pH) for each lake using the two transfer functions (equations) (both SR and GMR) derived from each of log index alpha (α) and log index B (Table 3). These four sets of inferred pH values are regressed on corresponding measured lake water pH values for the 34 lakes in "difference plots" (Fig. 7 and 8). The regression coefficient (r^2) of all scattergrams were very highly significant ($P < 0.001$); In Fig. 7 it is apparent that the regression of index alpha (α) inferred values versus measured (contemporary) values is not improved by employing the GMR transfer function. The regression coefficient for the difference plot derived from GMR inferred values is sligthly better than the plot derived from simple regression (SR) inferred values ($r^2 = 0.74$ versus 0.72, respectively), however, the slope of the simple regression plot is much closer to the 1:1 line (0.99 versus 0.86, respectively) and the standard error is lower (0.15 versus 0.47). Conversely the GMR transfer function slightly improves the correspondence between index B inferred pH and contemporary pH (Fig. 8). The GMR transfer function results in a higher correlation coefficient (0.77 versus 0.76), lower standard error (0.22 versus 0.27) and a slope closer to the 1:1 line (1.01 versus 0.89) for the GMR difference plot as compared to the SR derived values. Considering the simple regression approach only, the log alpha (α) equation had slightly poorer statistics, with an r^2 value of 0.69 and S_e of $\pm$ 0.44 (Fig. 7) as opposed to the higher r^2 of 0.80 and lower S_e of $\pm$ 0.35 for the log Index B regression (Fig. 8).

DISCUSSION

Lakes selected for survey were found to adequately represent the range in lake acidity identified for the island of Newfoundland (Scruton 1983, 1985) and

compared favorably with recent historical data used as the basis for lake selection. A listing of pH data for the paleolimnological survey in comparison to available pH data from inventory and monitoring surveys is contained in Table 4. It is noteworthy that the physical/chemical data used to characterize the study lakes was based on one mid-summer sample obtained in August 1984. This is a historical low flow period in the hydrological cycle for insular Newfoundland's freshwaters (Environment Canada 1985); a period which is also characterized by annual maximums for pH, alkalinity, base cations ($Ca^{+2} + Mg^{+2}$) and bicarbonate (Scruton 1986). Conversely, sulphate and colour (as a correlate of organic content) are usually low during mid summer largely due to retention of organic matter and sulphate in the watershed, in part, ascribed to vegetational uptake and also due to low runoff levels (Dovland and Semb 1978; Skartveit 1981). In short pH, alkalinity, calcium, magnesium, and bicarbonate values used to characterize the lakes are likely greater than annual mean values, while sulphate and correlates of organic content (colour, DOC, $COOH^-$) are likely less than annual means. This seasonal pattern was evident in a monthly sampling program on 22 salmon rivers in insular Newfoundland conducted from May 1981 to May 1982 (Scruton 1986). This is an important consideration when relating a single point-in-time sample to fossilized diatoms remains in surface sediments representing a much wider time frame (years).

Certainly an important consideration in evaluating the relationship between contemporary pH and fossil diatom assemblages is that the top 1 cm sampled in the surface sediment series may represent diatoms deposited under previous lake water conditions as well as those under present conditions (Charles 1985). Sedimentation (accumulation) rates for two Newfoundland lake cores that were dated by ^{210}Pb (see Part 2 of this report series) varied from 0.04 cm yr^{-1} to 0.16 cm yr^{-1} indicating the the top 1 cm contained 25.0 and 6.25 years of diatom accumulation, respectively. Certainly, 25 years is a considerable length of time for lake conditions to change, particularly considering the relatively recent onset of freshwater acidification in the Atlantic Region (Watt et al. 1979). Low alkalinity lakes would be expected to have most likely undergone recent pH changes and may be most prone to this type of error. The low accumulation rate of 0.04 cm yr^{-1} however is associated with the largest lake in the study and appears to be an artifact of watershed characteristics that are not representative of the entire data set.

There has been considerable discussion as to what pH value be used in comparison of contemporary pH with pH values inferred by the log Index alpha (α) and log Index B transfer functions. Some authors suggest that a mean value be used but the question arises as to how many values need be incorporated into mean values, and over what time frame. Merilainen (1967) suggests that only pH values taken after fall overturn be used in calibration models. In his work on 150 finish lakes, fall pH values produced the best relationship with the log of Nygaard's Index alpha (α). Batterbee (1984b) feels there is not a clear concensus on what pH value should be incorporated into the contemporary pH/inferred pH comparisons. A comparison between a mean pH value for the study lakes (from samples collected over the period August 1981 to October 1984) indicates pH values obtained during the paleo survey compared favourably with the mean values (with n ranging from 2 to 7). For 28 of 34 lakes the pH difference (x pH-paleo pH) is less than 0.3 of a unit with a maximmum difference of 0.42 unit for lake # 642.

Calibration indices derived from diatom floristic data have been successfully used to predict past lake water pH (Batterbee 1984a and b). However, regional differences in the response of diatom communities to pH have been reported (Dickman and Fortescue 1984). Howell and Lakshminarayana (1986) even noted appreciable differences in diatom - pH responses between small geographical areas in Nova Scotia. These regional differences can result in quite a large variation between regression equations used in predicting inferred pH's from preserved diatom sub-fossil data. To date, log index alpha (α) has been the most widely employed index and is therefore most useful in comparison to diatom assemblage/pH relationships from different global regions, primarily Northern Europe and Northeastern North America. The log alpha (α) transfer function (SR) from this study is compared with other published equations in Table 5. The slope of regression line for log alpha (α) verses contemporary pH for insular Newfoundland lakes (0.77) falls within the published range of 0.46 for Danish lakes (Nygaard 1956) to 0.82 for lakes north of Lake Superior (Dickman and Fortescue 1984). The Y-intercept of the equation for insular Newfoundland (6.45) also falls within the range established in the literature of 4.49 for lakes in Kejimikujik Park in Nova Scotia (Howell and Lakshminarayana 1986) to 6.97 for Danish lakes (Nygaard 1956).

It is apparent that the equation developed for log alpha (α) in this study of Newfoundland lakes falls well within the established range and is similar to an equation developed by Norton et al. (1981) for a series of lakes in northeastern U.S.A. The slope of the regression from Newfoundland lake data is only 0.02 greater than the value of 0.75 established for northeastern U.S.A. and the present intercept is only 0.12 higher than a value of 6.34 for the northeastern U.S.A. These two regions are geographically similar and both contain lakes highly influenced by natural organic acidity.

It is interesting to note that the slope of the log alpha (α) equation for this study (0.77) is identical to that determined for a small set of 8 insular Newfoundland lakes and for 15 Nova Scotian lakes (Howell and Lakshminarayana 1986). However, the intercepts in the latter two data sets are much lower than for this study (5.64 and 4.49 versus 6.45, respectively) and lower than any published for other regional data sets (see Table 5). The difference in the Y-intercept of the log index alpha (α) equation between for this study and the Howell and Lakshminarayana (1986) sample may, in part, be related to the larger sample size ($n = 34$ vs $n = 8$) and wider range in pH (4.86-7.72 vs 5.2-6.7) and associated variables in this study, as the range in colour values (10-87.5 vs 15-100) between studies is similar. The author's conclude that the lower Y-intercepts in the transfer functions developed from their data sets is an indication of the importance of organic contribution in determining pH-diatom relationships.

Similarly, the log index B transfer function from this study can be compared with other recently published equations (Table 6). The slope of the log Index B versus pH regression equation for insular Newfoundland lakes of 0.87 is the highest published to date although very close to the narrow published range of 0.83 for New England lakes (Davis and Anderson 1985) to 0.85 for Swedish (Renberg and Hellberg 1982), Norwegian (Davis and Anderson 1985), and Adirondack (Charles 1985) lakes. The Y-intercept of the Index B equation for insular Newfoundland lakes of 6.63 falls within the range of 6.40 for Swedish lakes (Renberg and Hellberg 1982) to 6.91 for Adirondack lakes (Charles 1985).

Basic to the calculation of regional equations for Log Index alpha (α) and Log Index B is the categorization of diatom species to pH tolerance groups after Hustedt (1937-1939). Most authors have assigned pH tolerance on the basis of ecological requirements derived from a review of the pertinent literature. In these instances comparisons of the Log Index alpha (α) and Log Index B transfer functions between regions are more valid because the diatom species indicator status has been established from a similar basis in literature for all regions. It follows that differences in slope and intercept of the regression equations would suggest that lakes in different regions of the world with similar pH are represented by diatom assembleges that differ slightly in either species composition or relative abundance of species.

Recently, Davis and Anderson (1985) have employed multiple linear regression, using relative frequencies of selected diatom taxa and the first principal component, to develop transfer functions. Such techniques can eliminate the problems of proper allocation of taxa to pH tolerance groups and require no prior classification of floristic data into pH tolerance categories. Charles (1985) and Davis and Anderson (1985) have found this method to yield slightly better regression statistics than index methods. Charles (1985) assigned pH indicator status for diatoms in Adirondack lakes on the basis of the literature and also by evaluating the distribution of taxa in the study area in relation to contemporary lake characteristics. He attributed differences in assignment of taxa to pH tolerance categories, particularly the placement of certain taxa to lower pH categories based on regional pH distribution, to indicate that certain taxa have developed relatively higher populations in the acidic waters of the Adirondacks than in other global regions. He felt the assignment method using contemporary lake characteristics more accurately reflected the distribution of taxa in the Adirondack Mountains region than did the literature references.

"Difference plots" of measured pH versus Index B inferred pH (Fig. 8) compared well with similar plots for sets of 31 and 35 lakes from northeastern U.S.A and Norway, where r^2 values of 0.57 and 0.65 and S_e of $\pm$ 0.42 and $\pm$ 0.36, respectively were obtained. A comparison of the two pH values for insular Newfoundland lakes yielded a r^2 of 0.76 (very highly significant at $P \leq 0.001$) and a $S_e \pm 0.27$ with the SR transfer function and a r^2 of 0.77 (very highly significant at $P \leq 0.001$) and a S_e of ± 0.22 with the GMR transfer function.

Inferred pH values derived from the index B transfer function, computed by geometric mean regression, provides better correspondence with measured lake pH than do values inferred by simple linear regression (Fig. 8). A comparison of the simple regression line with the 1:1 line indicate that the SR transfer function overestimates the pH in the lower pH ranges (pH 5.5 and less) and underestimates the pH in the upper pH ranges (pH 6.5 and greater). If this apparent bias is real, then inferences with respect to the amount of historical pH change as evidence of lake acidification (as determined from downcore pH profiles in Part 2 of this report series) will be underestimated by the simple linear regression transfer function. A comparison of historical pH profiles inferred from index B, using both the simple regression (SR) and geometric mean regression (GMR) transfer functions, will be examined in Part 2 of this report series.

Cluster analysis of selected taxa from the 34 surface sediment samples (Fig. 3) showed a clear division of lakes according to pH, both measured and Index B inferred, lending confidence to this method for past pH predictions and for assignment of insular Newfoundland taxa into proper pH tolerance category. Any index-related technique is totally dependent on the correct assignment of all major taxa to pH tolerance categories. Although such data are well documented in the literature (Lowe 1974; Beaver 1985), there may well be some variation in pH tolerances of individual diatom taxa according to location. For example, Dickman et al. (1984) found Cyclotella compta to behave as an acidophilous taxa in lakes of the Algoma district, Ontario. This centric species has been assigned to an indifferent category by Beaver (1981) and alkaliphilous category by Lowe (1974). In the present study, C. glomerata seems to be acting more as an acidobiont (being widely distributed at pHs of <5.5) than an acidophil, its normal tolerance group. This is unexpected as Cyclotella species are reported to be especially vulnerable to low pH (Battarbee 1984). This regional departure from normal distributions may be a function of the highly coloured waters associated with the lower pH lakes. On the other hand Semiorbis hemicyclus, normally abundant only at pH's below 5.5, has a much wider tolerance level in the study lakes being found in lakes ranging up to pH 6.48. Dixit and Dickman (1986) found the majority of the alkaline and acid tolerant taxa in Algoma Region lakes to follow their assigned pH tolerance categories. However, circumneutral taxa demonstrated discrepancies between assigned category and observed pH distributions.

Several authors have reported on the role of water colour as a determinant of diatom composition. Huttunen and Merilainen (1983), using cluster analysis, demonstrated that humic Finnish lakes contain unique diatom assemblages, while Davis et al. (1984) observed that several key diatom taxa were well correlated with organic carbon (TOC) concentrations in Norwegian lakes. For a data set of 17 lakes in insular Newfoundland, the regression coefficient of pH versus log alpha (α) improved when water colour was included in the multiple regression (r^2 = 0.49 and 0.61, respectively). Several authors (Vaughan et al. 1982, 1986; Delorme et al. 1982; Howell and Lakshminarayana 1986) have reported that highly coloured, low pH lakes in Nova Scotia have diatom assemblages containing a higher proportion of species defined as alkaliphilous (in the literature) than contemporary pH values would suggest. Earle and Duthie (1984) however have found whole water phytoplankton assemblages, including diatoms, from insular Newfoundland lakes to be regulated by several highly interdependent environmental variables, making it difficult to isolate the role of one variable.

The log alpha (α) index has been criticized on the grounds that it makes no account of circumneutral taxa, except in the indirect sense that they influence the percentage of other groupings (Renberg and Helberg 1982). When the circumneutral taxa are included, a small percentage change between the various groups can produce a large change in the index without there being a corresponding variation in nature. This may well account for some of the deviation of lakes from the regression line on the present log index alpha (α) versus pH scattergram (Fig. 5). More than half of the 24% of lakes that lie outside the bounds of the S_e (± 0.35 pH units) have a very high proportion of circumneutral taxa (Fig. 5). The log Index B versus pH scattergram (Fig. 6) indicates that 88% of the lakes fall within the S_e of ± 0.33 pH units

(for the SR). Index B is further considered to be a superior index to the Index alpha (α) because it incorporates more information (more pH tolerance groups) into its calculation and is not as sensitive to variations in the numbers of alkalaphilic taxa (Charles 1985). In addition, if no alkalibionts or alkalaphils are present in a sediment sample, as in extremely acidic lakes, Index alpha (α) cannot be calculated, therefor, biasing the ability of the log Index alpha (α) transfer function in inferring the pH of very acidic lakes (Davis and Anderson 1985; Dickman et al. 1984).

CONCLUSIONS

The transfer functions developed from fossil diatoms in surface sediments using Log Index alpha (α) and Log Index B compared favorably with those developed from other regional data sets. Regression slopes and Y-intercepts were different from other regions confirming the need to develop region-specific transfer functions for diatom/pH relationships. Index B is considered to be a superior index to Index alpha (α) by several authors (Charles 1985, Davis and Anderson 1985) and, for insular Newfoundland, the pH-Log Index B (SR) relationship gave better regression statistics and contained few outliers than did the pH-Log alpha (α) (SR) relationship. For index B, the transfer function computed by geometric mean regression (GMR) provided better correspondence between measured and inferred pH than did the transfer function developed by simple linear regression (SR). In Part 2 of this report series, historical pH profiles will be developed for seven lakes using the Index B transfer functions derived in this report.

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Table 1. Selected morphometric and physical characteristics of the 35 study lakes. The number of diatoms frustules counted is in ( ) beside lake number.

Lake No.	Surface area (ha)	Watershed area (ha)	Lake order	Ratio (WA:LSA)	Apparent maximum depth (m)	Secchi transparency (m)	Elevation (m)
1 (723)	147	706	1	4.8	2.5	2.5	30.5
2 (1000)	23	205	1	8.9	4.7	4.2	38.1
8 (1134)	104	617	1	5.9	4.0	3.0	297.2
11 (670)	232	660	1	2.8	20.0	5.0	57.9
12 (852)	25	167	1	6.7	12.0	1.0	403.9
14 (1026)	50	643	1	12.9	13.0	1.5	393.2
21 (743)	33	404	1	12.2	3.3	1.7	114.3
201 (565)	98	700	1	7.1	15.7	3.3	297.2
202 (902)	34	197	1	5.8	21.0	5.5	464.8
203 (741)	24	127	1	5.3	5.5	3.5	419.1
204 (675)	23	257	1	11.2	20.0	2.0	312.4
209 (562)	88	591	1	6.7	2.2	2.2	256.0
211 (895)	95	1209	1	12.7	3.3	2.5	280.4
215 (739)	87	508	1	5.8	23.0	3.8	131.1
217 (788)	244	1010	1	4.1	10.1	4.2	236.2
219 (571)	1117	6478	1	5.8	3.2	2.5	167.6
220 (473)	385	2180	2	5.7	5.2	4.7	175.3
225 (856)	116	577	1	3.5	9.5	9.5	205.7
253 (528)	37	231	1	6.2	20.0	3.5	283.5
606 (366)	20	146	1	7.3	2.0		304.8
632 (899)	190	630	1	3.3	4.0		480.1
638 (853)	60	190	1	3.2	15.0		434.3
641 (1139)	100	240	1	2.4	3.0		358.1
642 (970)	110	406	1	3.7	12.0		449.6
653 (967)	280	1202	5	4.3	2.5		281.9
660 (655)	164	752	2	4.6	8.0		266.7
665 (873)	26	308	2	11.8	1.0		205.7
668 (485)	104	604	1	5.8	5.0		251.5
669 (603)	238	554	1	2.3	1.0		175.3
670 (565)	16	144	1	9.0	1.0		236.2
671 (714)	6	15	2	2.6	1.0		175.3
672 (849)	10	110	2	11.0	9.0		312.4
675 (565)	88	376	3	4.3	1.5		251.5
678 (580)	26	108	1	4.2	2.5		190.5

Table 2. Selected physical and chemical characteristics of the 34 study lakes (from samples collected August 14 to 20, 1984).

Lake No.	pH	Alkal.	Conduct. ($\mu S\ cm^{-1}$)	Colour (TCU)	$COOH^-$	Ca^{+2}	Mg^{+2}	Na^+	K^+	Cl^-	SO_4^{-2}	Al ($\mu g\ L^{-1}$)
1	7.72	1715	198.0	10	41.7	1473	446	174	5	189	56	below det
2	7.42	1326	149.0	10	61.3	1080	276	126	7	127	40	34
8	5.34	14	13.6	10	29.9	20	19	61	4	59	23	156
11	7.26	915	130.0	10	39.4	753	345	174	8	198	75	10
12	5.13	5	13.6	50	47.5	19	18	48	4	48	19	129
14	5.23	18	14.4	60	56.8	22	21	52	4	48	19	192
21	7.10	674	94.0	60	76.5	498	293	170	9	158	56	99
201	6.04	34	31.2	50	62.7	77	50	135	5	141	42	109
202	6.42	45	26.2	15	30.4	104	29	91	1	96	33	59
203	5.22	6	15.6	15	25.9	24	16	65	1	54	25	99
204	5.13	9	15.5	50	46.0	32	19	65	4	54	31	134
209	6.19	68	19.5	10	44.9	97	22	61	2	56	17	22
211	5.65	27	13.0	20	41.2	32	17	61	3	48	17	66
215	5.51	10	22.8	20	34.3	36	30	117	3	118	33	136
217	5.45	9	16.1	17.5	32.2	30	21	70	2	73	25	54
219	5.62	11	19.2	17.5	41.9	39	26	87	6	85	27	82
220	5.68	52	16.8	17.5	33.5	31	20	87	3	79	29	72
225	5.85	40	17.7	10.0	14.4	34	19	87	3	79	33	62
253	7.45	1222	131.0	15.0	49.4	833	420	96	5	87	60	24
606	5.37	32	23.7	87.5	107.7	75	39	96	5	70	54	254
632	5.46	5	13.5	15.0	24.6	24	17	61	3	56	27	49
638	5.30	32	12.5	17.5	23.9	22	15	48	2	48	27	84
641	4.94	25	14.6	30.0	39.2	17	14	52	1	45	38	219
642	5.31	13	11.3	15.0	20.6	18	13	48	2	45	19	48
653	5.81	23	13.0	17.5	32.3	41	13	52	2	42	31	65
660	5.46	11	13.6	15.0	30.6	26	16	57	3	56	19	60
665	5.18	-5	14.4	50.0	48.9	22	20	57	3	51	17	150
668	6.43	88	20.3	25.0	51.4	91	62	44	3	34	13	32
669	5.67	31	20.0	70.0	91.5	70	35	78	3	62	19	197
670	4.87	26	16.6	75.0	57.0	19	17	61	1	54	19	149
671	4.86	7	18.2	75	65.7	25	20	70	3	56	19	244
672	5.19	29	16.1	50	46.6	28	17	65	3	56	27	125
675	5.61	22	13.2	25	47.0	27	31	39	3	39	17	89
678	5.15	2	12.8	15	25.5	17	16	48	1	48	13	20

All values in $\mu eq\ L^{-1}$ unlesss otherwise stated.

Table 3. Equations and statistics for simple linear regression (SR) and geometric mean regression (GMR) of 1) log index alpha (α) and 2) log index B versus contemporary pH for the 34 Newfoundland study lakes. Significance of r^2 as determined by Student's "t" test (Nie et al. 1975).

	Regression Equation	r^2	S_e	Significance
1. log index alpha (α) (SR)	pH = 6.45-0.77 log α	0.73	± 0.35	P < 0.001
log index alpha (α) (GMR)	pH = 6.60-0.90 log α	0.73	± 0.41	P < 0.001
2. log index B (SR)	pH = 6.63-0.87 log B	0.77	± 0.33	P < 0.001
log index B (GMR)	pH = 6.70-0.98 log B	0.77	± 0.38	P < 0.001

Table 4. A comparison of pH values obtained in the Paleolimnoloigcal survey (August 1984) with pH data obtained in lake inventories and monitoring programs (August 1981 to November 1985).

Lake No.	pH Paleo-study	$\bar{X}$pH	Range	n	Sampling dates
1	7.72	8.06	7.72-8.39	2	09-81 to 08-84
2	7.42	7.80	7.42-8.17	2	09-81 to 08-84
8	5.34	5.36	5.34-5.37	2	09-81 to 08-84
11	7.26	7.66	7.26-8.05	2	10-81 to 08-84
12	5.13	5.02	4.90-5.13	2	10-81 to 08-84
14	5.23	5.17	5.10-5.23	2	10-81 to 08-84
21	7.10	7.28	7.10-7.46	2	10-81 to 08-84
201	6.04	5.85	5.58-6.04	3	10-81 to 08-84
202	6.42	6.75	6.42-7.02	6	10-81 to 11-85
203	5.22	5.45	5.22-5.79	7	10-81 to 11-85
204	5.13	5.21	5.00-5.49	7	10-81 to 11-85
209	6.19	6.32	5.80-6.94	6	09-81 to 11-85
211	5.65	5.80	5.59-6.06	6	08-81 to 08-84
215	5.51	5.64	5.51-5.76	2	08-81 to 08-84
217	5.45	5.51	4.78-6.00	7	08-81 to 10-84
219	5.62	5.96	5.62-6.18	5	08-81 to 10-84
220	5.68	5.82	5.68-5.98	3	08-81 to 08-84
225	5.85	5.79	5.14-6.42	4	08-81 to 10-84
253	7.45	7.63	7.45-7.81	2	09-81 to 08-84
606	5.37	5.66	5.37-5.89	3	07-83 to 08-85
632	5.46	5.52	5.46-5.58	2	07-83 to 08-84
638	5.30	5.66	5.30-6.02	2	07-83 to 08-84
641	4.94	4.93	4.55-5.19	8	07-83 to 08-85
642	5.31	5.73	5.31-6.30	4	07-83 to 08-85
653	5.81	5.91	5.68-6.10	4	07-83 to 08-85
660	5.46	5.66	5.46-5.90	5	07-83 to 08-85
665	5.18	5.21	4.91-5.60	7	07-83 to 08-85
668	6.43	6.54	6.43-6.65	2	07-83 to 08-84
669	5.67	5.57	5.13-5.97	5	07-83 to 08-85
670	4.87	4.88	4.57-5.21	4	07-83 to 08-85
671	4.86	4.81	4.60-4.99	5	07-83 to 08-85
672	5.19	5.11	4.82-5.35	4	07-83 to 08-85
675	5.65	5.94	5.65-6.22	2	07-83 to 08-84
678	5.15	5.28	5.15-5.40	2	07-83 to 08-84

Table 5. Equations for log Index alpha (α) vs contemporary pH from different global regions.

Equation	r^2	S_e	No. of lakes	pH range	Location	Reference
pH = 6.97-0.46 log Index α			13		Denmark	Nygaard 1956
pH = 6.71-0.81 log Index α			12		Finland	Merilainen 1967 (in Dickman et al. 1981)
pH = 6.28-0.58 log Index α	0.57	±0.51	31	4.4-7.0	N. New England	Davis and Anderson 1985
pH = 6.56-0.64 log Index α	0.65	±0.44	36	4.4-7.1	Norway	Davis and Anderson 1985
pH = 6.63-0.81 log Index α[a]			32		Adirondack Mountains, Denmark, and Finland	Del Prete and Scholfield 1981
pH = 6.57-0.82 log Index α	0.79		28	4.6-8.2	North of Lake Superior	Dickman et al. 1983
pH = 6.81-0.70 log Index α	0.91	±0.33	38	4.5-7.8	Adirondack Mountains	Charles 1985
pH = 4.49-0.77 log Index α	0.67		15	4.3-5.9	Kejimikujik Park in Nova Scotia	Howell and Lakshminarayana 1986
pH = 5.64-0.77 log Index α	0.87		8	5.2-6.7	South and West Coast of Newfoundland	Howell and Lakshminaraynan 1986
pH = 6.45-0.77 log Index α	0.73	0.35	34	4.86-7.72	Insular Newfoundland	This study

[a]Equation determined for 7 Adirondack lakes and data from Nygaard (1956) and Merilainen (1967).

Table 6. Equations for log Index B vs contemporary pH from different global regions.

Equation	r^2	S_e	No. of lakes	pH range	Location	Reference
pH = 6.40-0.85 log Index B	0.91	±0.30	30	4.3-7.2	S.W. Sweden	Renberg and Hellberg 1982
pH = 6.42-0.83 log Index B	0.72	±0.42	31	4.4-7.0	N. New England	Davis and Anderson 1985
pH = 6.57-0.85 log Index B	0.76	±0.36	36	4.4-7.1	Norway	Davis and Anderson 1985
pH = 6.91-0.85 log Index B	0.93	±0.30	38	4.5-7.8	Adirondack Lakes	Charles 1985
pH = 6.63-0.87 log Index B	0.77	±0.33	34	4.86-7.72	Insular Newfoundland	This study

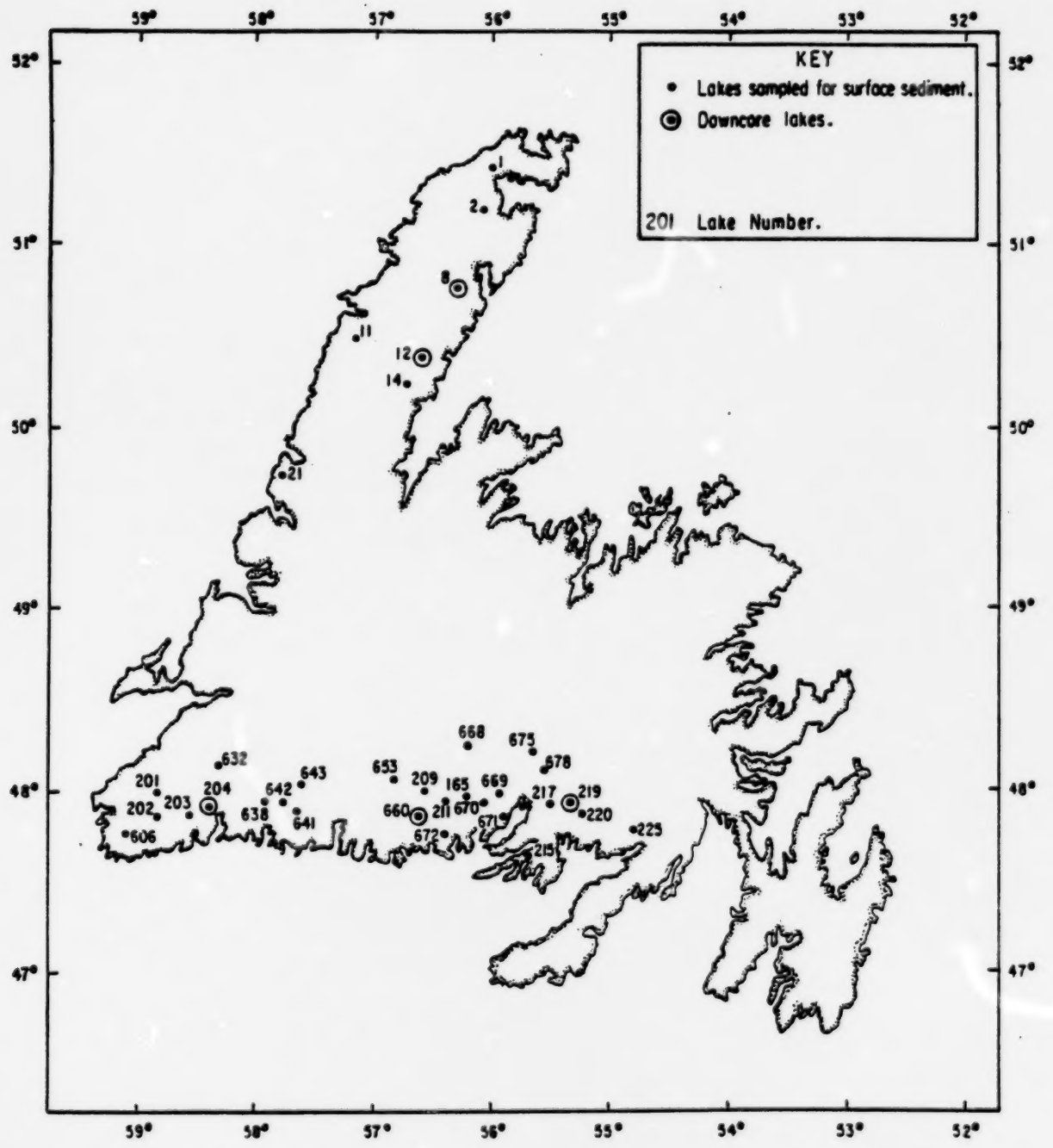

Fig. 1. Map of Insular Newfoundland showing lakes sampled in the paleolimnological survey, August 1984.

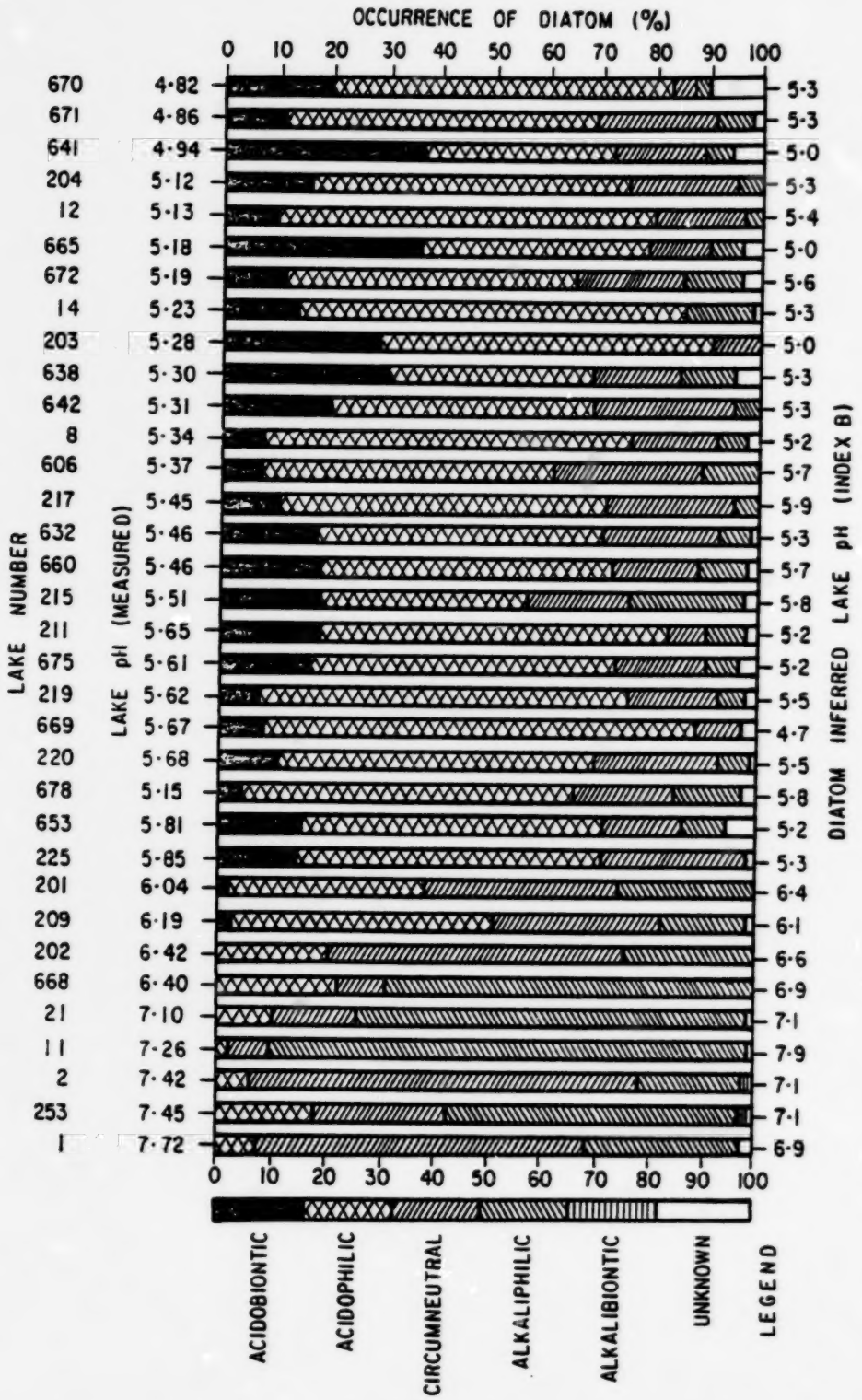

Fig. 2. Variation in pH tolerance groups (as acidobionts, acidophilis, etc.) for the study lakes, including measured and index B inferred pH.

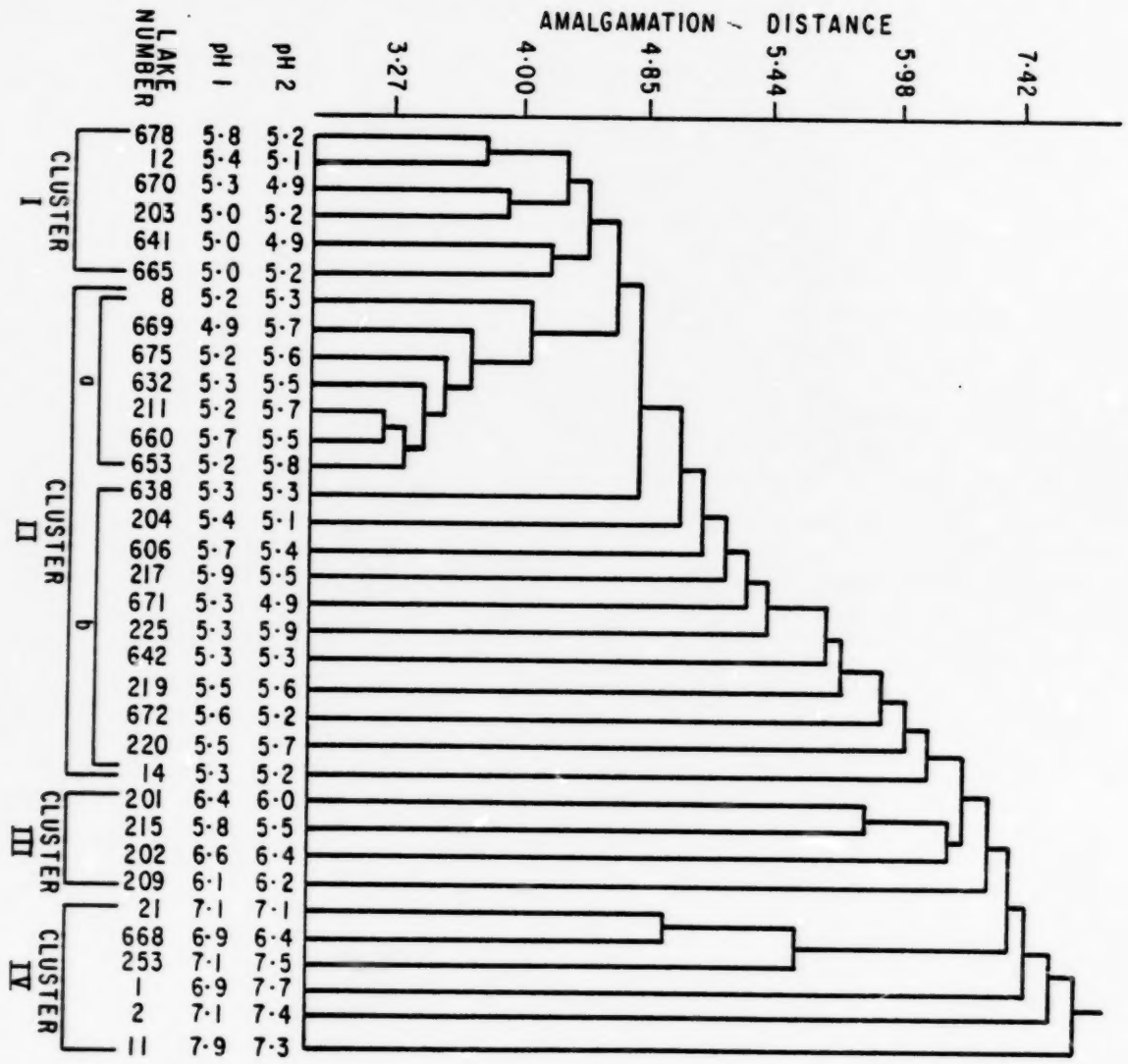

Fig. 3. Cluster analysis of the diatom floristic data from surface sediments in the 34 study lakes. Amalgamation distance is derived from the distance between chi-square values. Note pH: 1 = Index B (SR) inferred value, pH 2 = measured value.

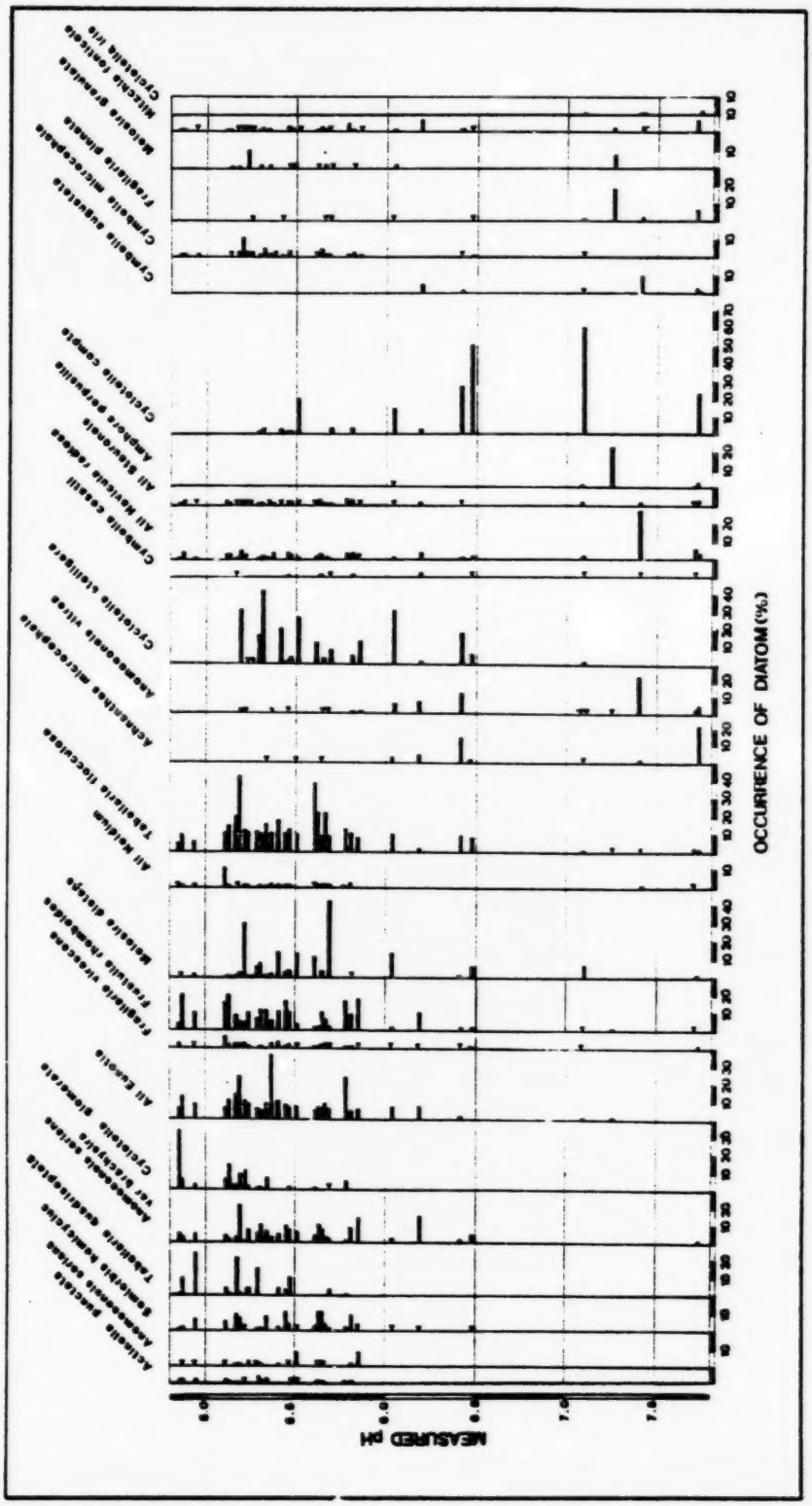

Fig. 4. Relative frequencies of the most commonly occurring diatom taxa versus measured pH in the study lakes.

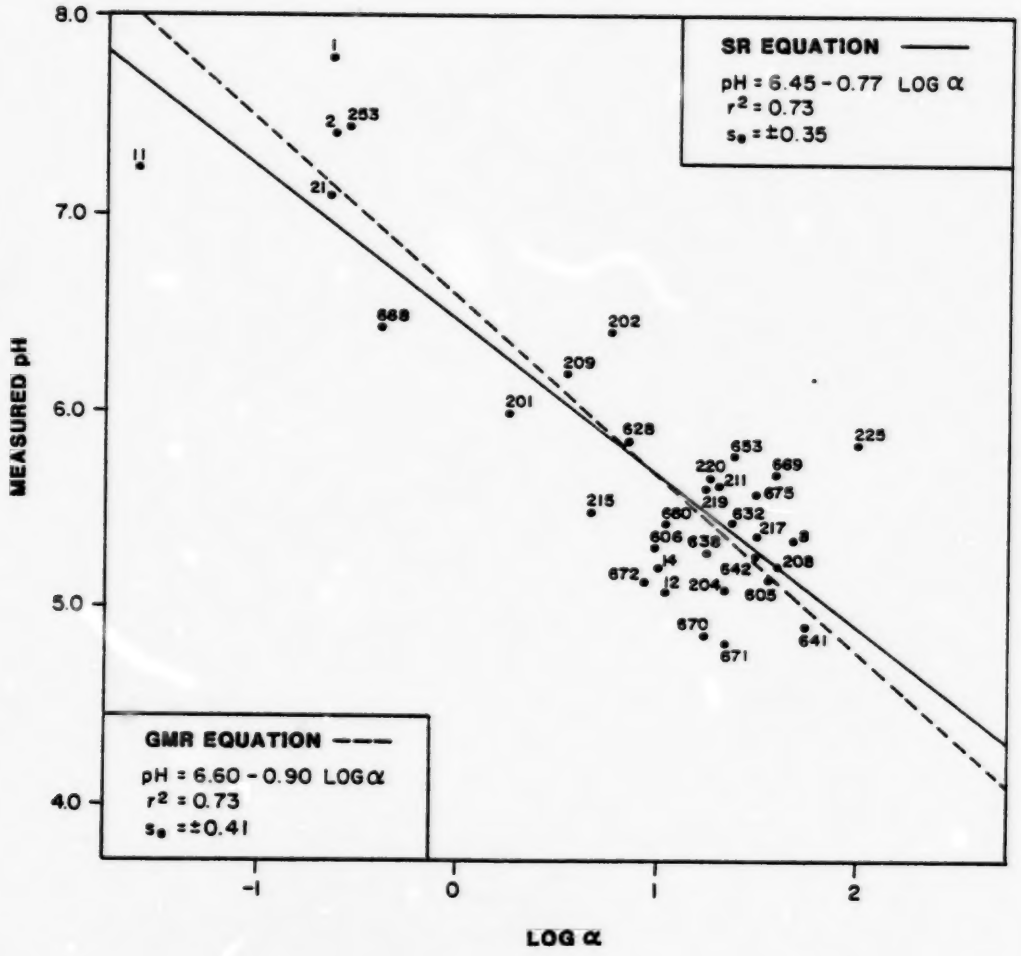

Fig. 5. Log_{10} Index alpha (α) versus measured pH in the study lakes. Both simple linear regression (SR) and geometric mean regression (GMR) equations and lines are shown.

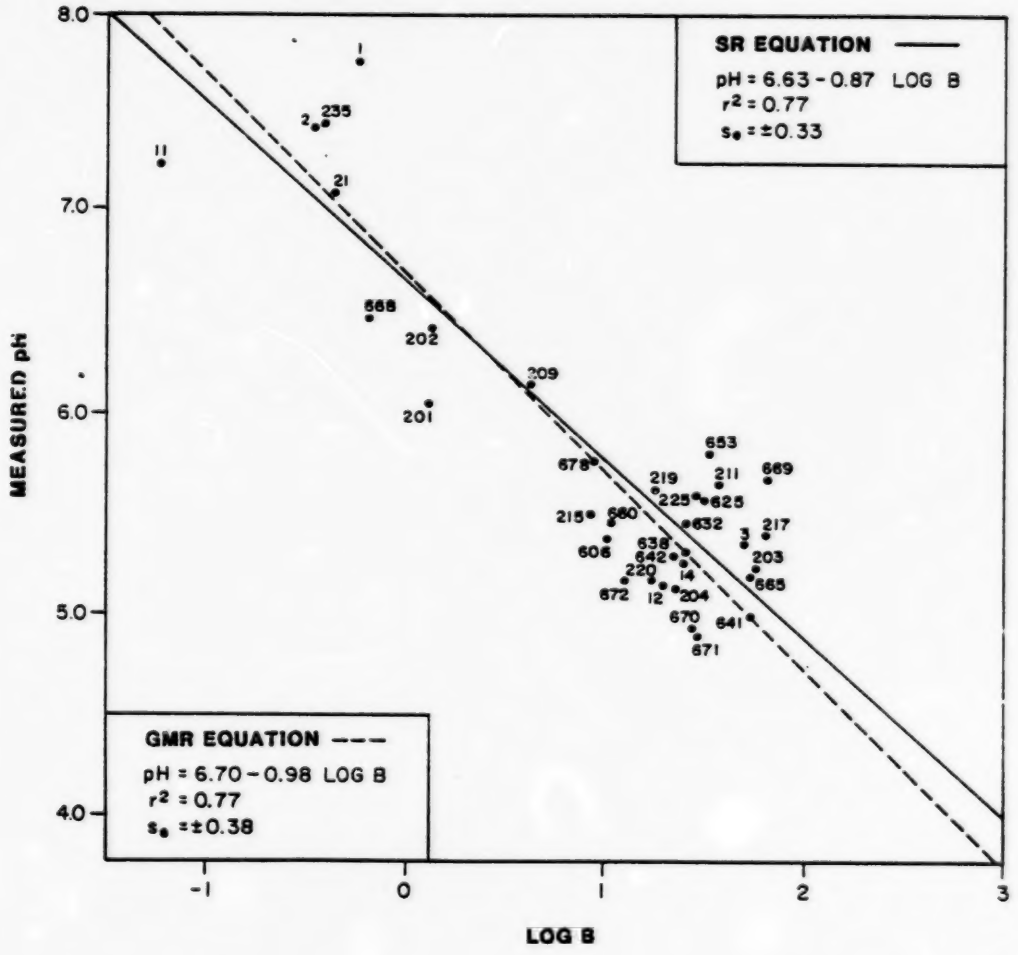

Fig. 6. Log_{10} Index B versus measured pH in the study lakes. Both simple linear regression (SR) and geometric mean regression (GMR) equations and lines are shown.

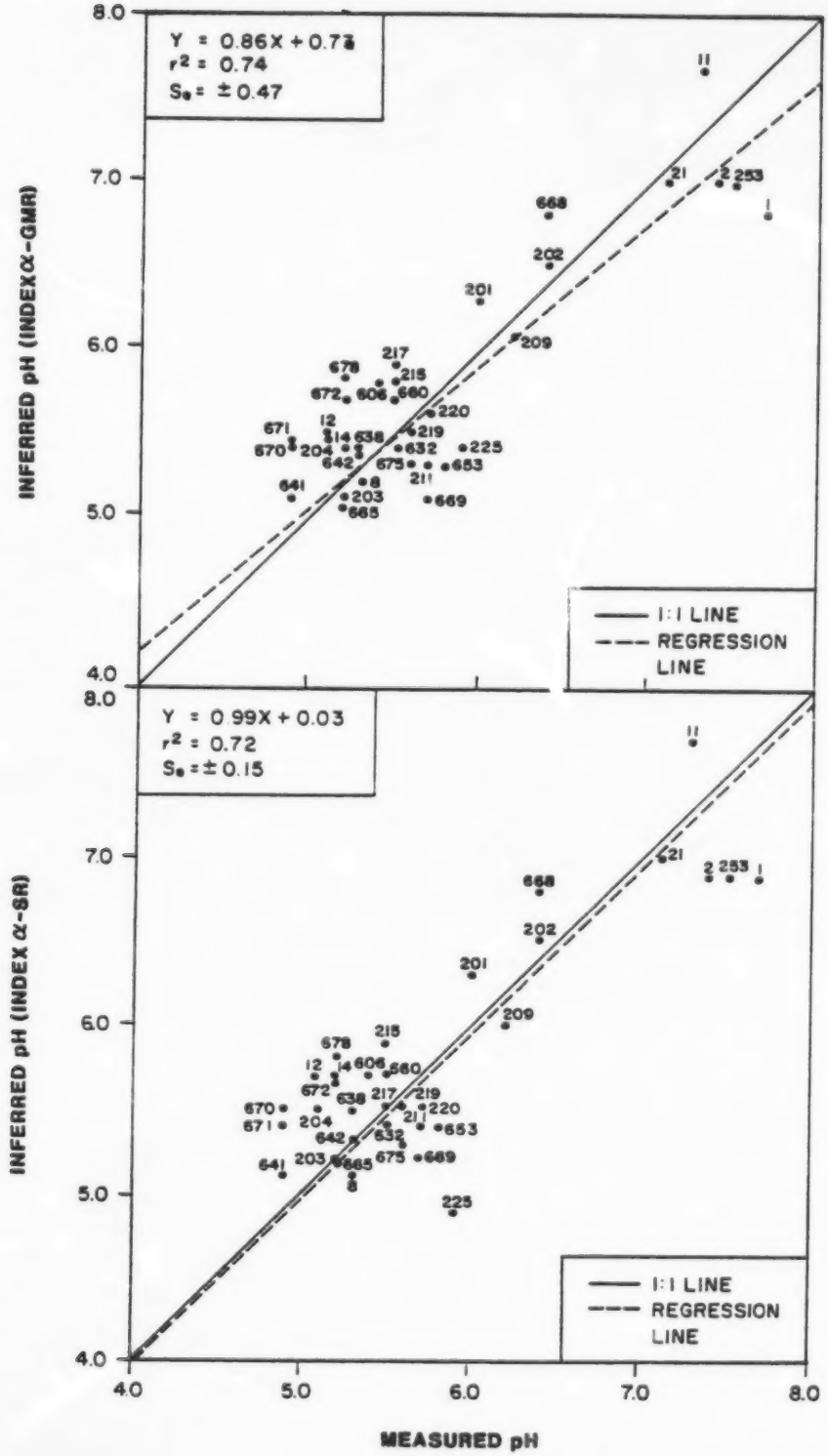

Fig. 7. "Difference plot" for measured pH versus $\log_{10}$ Index alpha (α) inferred pH using both the simple linear regression (SR) and geometric mean regression (GMR) transfer functions.

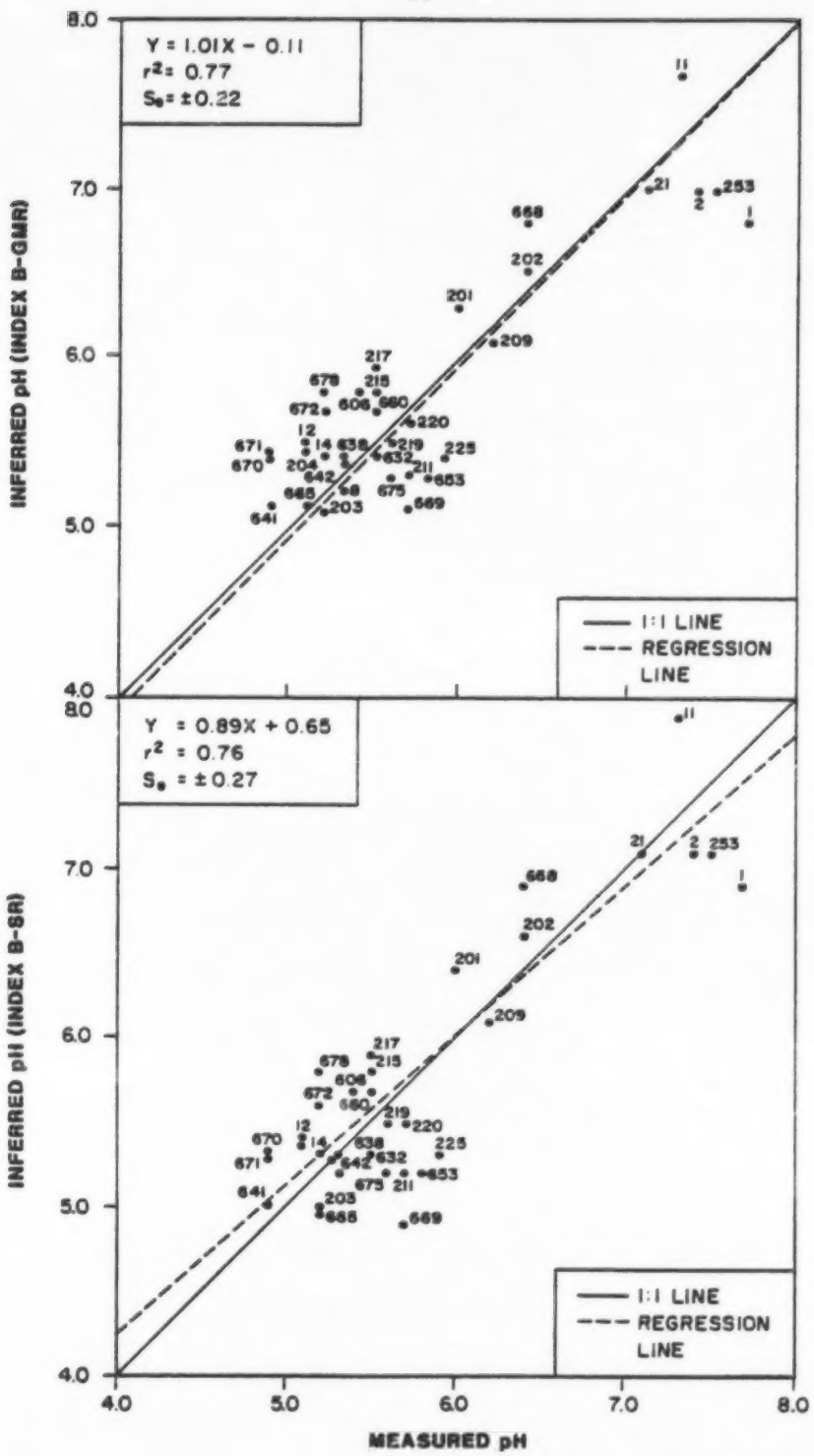

Fig. 8. "Difference plot" for measured pH versus $\log_{10}$ Index B inferred pH using both the simple linear regression (SR) and geometric mean regression (GMR) transfer functions.

Appendix 1. List of diatom species with taxonomic reference and assigned pH category.

Alkb - Alkalibiontic
Alk - Alkaliphilous
C - Circumneutral
Ac - Acidophilous
Ab - Acidobiontic
* - Occurrence in DFO downcores only
** - Occurrence in DOE downcores only

P and R - Patrick and Reimer (1966, 1975)
M and T - Molder and Tynni (1967-1973)
H - Hustedt (1937-1939)
T - Tynni (1975-1981)
R - Renberg (1977)
L - Lortie (1983)

Species	Reference	pH
Achnanthes		
austriaca Hust.	H, 1930: 201, Fig. 285	Alk
calcar Cleve	M and T, VI, 1972: 145, pl. /28	Alk
clevei v. rostrata Hust.	P and R, 1966: 267, pl. 17/23-24	Alk
didyma Hust.	M and T, VI, 1972: 147, pl. iii/36	**
exigua Grun.	P and R, 1966: 257, pl. 16/21-22	Alk
exigua v. constricta (Grun.) Hust.	P and R, 1966: 258, pl. 16/23-24	Alk
flexella (Kütz.) Brun	P and R, 1966: 260, pl. 16/31-32	C
flexella v. alpestris Brun.	M and T, VI, 1972: 148, pl. 111/46	C
lanceolata (Breb.) Grun.	P and R, 1966: 269, pl. 18/1-10	Alk
lanceolata v. dubia Grun.	P and R, 1966: 271, pl. 18/11-15	Alk**
lanceolata v. unknown		
lavanderi Hust.	P and R, 1966: 262, pl. 17/3-4	AC
linearis (W. Sm.) Grun.	P and R, 1966: 251, pl. 16/3-4	Ac
marginulata (Kütz.) Grun.	P and R, 1966: 261, pl. 17/1-2	Ac
microcephala (Kütz.) Grun.	P and R, 1966: 250, pl. 16/1-2	C
minutissima Kütz.)	P and R, 1966: 253, pl. 16/9-10	C

. . . Cont'd.

Species	Reference	pH
peragalii Brun. and Hérib.	P and R, 1966: 274, pl. 19/1-2	C
sp		
Actinella		
punctata Lewis	P and R, 1966: 222, pl. 14/14	Ab
Anomoeoneis		
exilis f. lanceolata A. Mayer	M and T, VII, 1973: 166, pl. v/52	C**
follis (Ehr.) Cl.	P and R, 1966: 376, pl. 32/4	C
serians (Bréb. ex Kütz.) Cl.	P and R, 1966: 378, pl. 33/1	Ab
serians v. acuta Hust.	P and R, 1966: 378, pl. 33/2	Ac
serians v. brachysira (Bréb. Kütz.) Hust.	P and R, 1966: 379, pl. 33/7-11	Ac
styriaca (Grun.) Hust.	P and R, 1966: 382, pl. 33/15	Ac
vitrea (Brun.) Ross	P and R, 1966: 380, pl. 33/12-13	C
zellensis (Grun.) Cl.	P and R, 1966: 381, pl. 33/14	
Asterionella		
formosa Hass.	P and R, 1966: 159, pl. 9/1-3	Alk
ralfsii v. americana Korner.	L. 1983: pl. 1. 9/10	Ab
Amphora		
ovalis Kütz.	P and R, 1972: 68, pl. 13/1-2	Alk
ovalis v. pediculus (Kütz.) V.H. ex DeT.	P and R, 1972: 69, pl. 13/5a-6b	Alk**
ovalis v. affinis (Kütz.) V.H. ex DeT.	P and R, 1972: 69, pl. 13/3-4	Alk
perpusilla (Grun.) Grun.	P and R, 1972: 70, pl. 13/8a-11b	Alk
sp		

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Species	Reference	pH
Caloneis		
ventricosa (Ehr.) Meist.	P and R, 1966: 583, pl. 54/3	C**
ventricosa v. alpina (Cl.) Patr. comb. Nov.	P and R, 1966: 583, pl. 54/1	Alk**
ventricosa v. subundulata (Grun.) Patr. Comb. Nov.	P and R, 1966: 584, pl. 54/4	Alk**
venticosa v. truncatula (Grun.) Meist	P and R, 1966: 585, pl. 54/5	Alk
sp 1		
Cocconeis		
placentula Ehr.	P and R, 1966: 240, 1. 15/7	Alk
placentula v. lineata (Ehr.) V.H.	P and R, 1966: 242, pl. 15/5-6	C**
scutellum v. parva Grun.	M and T, VI, 1972: 143, Pl. 11/17a-b	Alk
Coscinodiscus		
lacustris Grun.	M and T, V, 1968: 159, pl. IV/25a-c	C
sp 1		
Cyclotella		
antiqua W. Sm.	M and T, V. 1968: 151, pl. 1/1	Ac
arentii Kolbe	M and T, V, 1968: 151, pl. 1/2	Alk
bodanica Eulenst	H, 1930: 103, Fig. 76	Alk

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Species	Reference	pH
comta (Ehr.) Kütz.	M and T, V, 1968: 152, pl. 1/4a-b	Alk
comta v. oligactis (Ehr.) Grunow	M and T, V, 1968: 152, pl. 1/5	Alk
glomerata Bachmann	H, 1930: 107, Fig. 81	Ac
iris Brun.	M and T, V, 1968: 153	Alkb
kützingiana Thwaites	M and T, V, 1968: 153	C
meneghiniana Kütz.	M and T, II, 1968: 154, pl. 11/9a-b	Alk**
ocellata Pant	M and T, V, 1968: 154	C
stelligera (Grun.) Cl	M and T, V, 1968: 155	C
Cymbella		
augustata (W. Sm.) Cl	P and R, 1975: 22, pl. 3/3-5	Alk
cesatii(Rabh.) Grun. ex A.S.	P and R, 1975: 21, pl. 3/1-2	C
cistula v. gibbosa Brun.	P and R, 1972: 63, pl. 11/5-7	**
cuspidata Kütz.	P and R, 1975: 39, pl. 6/2-3	C
lunata W. Sm.	P and R, 1975: 46, pl. 7/11-14	Ac
microcephala Grun.	P and R, 1975: 33, pl. 4/12a-13b	Alk
minuta Hilse ex Rabh.	P and R, 1975: 47, pl. 8/1-4	C
minuta f. latens (Krasske) Reim.	P and R, 1975: 49, pl. 8/5a-6b	C
minuta v. silesiaca (Bleisch ex Rabh.) Reim.	P and R, 1975: 49, pl. 8/7a-10b	C
naviculaformis Auerswald	P and R, 1975: 31, pl. 4/9	
sinuata f. antiqua (Grun.) Reim. stat. nov.	P and R, 1975: 51, pl. 9/5a-b	C
sp		

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Species	Reference	pH
Denticula		
elegans Kütz.	P and R, 1975: 170, pl. 22/1-2	Alk
subtilis Grun.	P and R, 1975: 172, pl. 22/10-11	Alk
tenuis v. cassula (Naeg. ex Kütz.) + West	P and R, 1975: 173, pl. 22/14-15	Alk
Diatoma		
anceps (Ehr.) Grun.	P and R, 1966: 106, p.. 2/1-3	Alk**
hiemale (Roth) Herib.	P and R, 1966: 107, pl. 2/7	Alk
tenue v. elongatum Lyngb	P and R, 1966: 109, pl. 2/6	Alk
Diploneis		
boltiana Cleve.	M and T, VII, 1972: 161, pl. 11/14	
elliptica (Kütz.) Cl.	P and R, 1966: 414, pl. 38/9	C
finnica (Ehr.) Cl.	P and R, 1966: 410, pl. 38/1	*
marginestriata Hust.	M and T, VII, 1972: 163, pl. iii/27	Ac
oblongella (Naeg. ex Kütz) Ross	P and R, 1966: 413, pl. 38/8	Alk**
pseudovalis Hust.	P and R, 1966: 412, pl. 38/5	
puella (Schum.) Cl.	P and R, 1966: 414, pl. 38/9	Alk
smithii (Bréb. ex W. Sm.) Cl.	P and R, 1966: 410, pl. 38/2	
smithii v. dilatata (M. Perag.) Boyer	P and R, 1966: 411, pl. 38/3	
Epithemia		
adnata (Kütz.) Bréb.	P and R, 1975: 179, pl. 24/3-4	Alk
adnata v. proboscidea (Kütz.) Patr.	P and R, 1975: 181, pl. 24/5	Alk

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Species	Reference	pH
smithii Carruthers	P and R, 1975: 187, pl. 27/3a-b	Alk
turgida (Ehr.) Kütz.	P and R, 1975: 182, pl. 25/1a-b	Alk
Eunotia		
arcus Ehr.	P and R, 1966: 212, pl. 13/11	Ac
arcus v. *bidens*	P and R, 1966: 213, pl. 13/12	C**
bactriana Ehr.	P and R, 1966: 219, pl. 14/9	Ac
bidentula W. Sm.	P and R, 1966: 202, pl. 12/5	Ab
bigibba Kütz.	M and T, V, 1971: 206, pl. 11/16a-b	Ab*
curvata (Kütz.) Lagerst.	P and R, 1966: 189, pl. 10/4	Ac
diodon Ehr.	P and R, 1966: 204, pl. 12/7	Ac
elegans Ostr.	P and R, 1966: 211, pl. 13/9	Ac
exigua (Bréb. *ex* Kütz.) Rabh.	P and R, 1966: 215, pl. 13/17-18	Ab
fallax A. Cl.	P and R, 1966: 214, pl. 13/15	Ab
flexuosa Bréb. *ex* Kütz.	P and R, 1966: 187, pl. 10/1	Ab
formica Ehr.	P and R, 1966: 190, pl. 10/7	C
hexaglyphis Ehr.	P and R, 1966: 203, pl. 12/6	C
incisa W. Sm. *ex* Greg.	P and R, 1966: 208, pl. 13/4	Ac
indica Grun.	P and R, 1966: 195, pl. 11/2	Ac
maior (W. Sm.) Rabh.	P and R, 1966: 196, pl. 11/5	Ac
meisteri Hust.	P and R, 1966: 216, pl. 14/2	Ab
microcephala Krasske *ex* Hust.	P and R, 1966: 216, pl. 14/3	Ab
monodon Ehr.	P and R, 1966: 198, pl. 11/6	Ab
naegleii Migula	P and R, 1966: 190, pl. 10/6	Ac

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Species	Reference	pH
paludosa Grun.	L, 1983: 163, pl. ii/1-10	Ab**
paludosa v. pumila Cleve-Euler	L, 1983: 166, pl. iv/2-8	Ac
papilio (Grun.) Hust	H, 1930: 173, Fig. 209	Ac
parallela Ehr.	P and R, 1966: 193, pl. 10/12	C
pectinalis (O.F. Mull.?) Rabh.	P and R, 1966: 204, pl. 12/8, 10	Ac
pectinalis v. minor (Kütz.) Rabh.	P and R, 1966: 207, pl. 12/13-14	Ac
pectinalis v. undulata (Ralfs) Rabh.	P and R, 1966: 206, pl. 12/11	Ac
pectinalis v. ventricosa (Grun.)	P and R, 1966: 205, pl. 12/9	Ac
perpusilla Grun.	P and R, 1966: 218, pl. 14/6	Ac
praerupta Ehr.	P and R, 1966: 193, pl. 10/14	Ac
praerupta v. bidens (Ehr.) Grun.	P and R, 1966: 194, pl. 10/13	Ab**
praerupta v. inflata Grun.	P and R, 1966: 194, pl. 10/15	Ac
rostellata Hust. ex Patr.	P and R, 1966: 191, pl. 10/9	Ac*
septentrionalis Ostr.	P and R, 1966: 212, pl. 13/10	Ac
serra Ehr.	P and R, 1966: 200, pl. 12/2	Ac
serra v. diadema (Ehr.) Patr.	P and R, 1966: 201, pl. 12/3	Ac
sudetica O.F. Mull.	P and R, 1966: 208, pl. 13/3	Ac
suecica A. Cl.	P and R, 1966: 199, pl. 11/9	Ac
tautoniensis Hust. ex Patr.	P and R, 1966: 191, pl. 10/8	Ac
tenella (Grun.) Cl.	P and R, 1966: 210, pl. 13/6	Ac
trinacria Krasske	P and R, 1966: 218, pl. 14/4	Ab
vanheurckii Patr.	P and R, 1966: 210, pl. 13/7	Ac
vanheurckii v. intermedia Krasske ex Hust.) Patr.	P and R, 1966: 211, pl. 13/8	Ac

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Species	Reference	pH
Fragilaria		
brevistriata v. inflata (Pant.) Hust.	P and R, 1966: 129, pl. 4/16	Alk
capucina Desm.	M and T, IV, 1970: 130, pl. 1/5a-b	Alk
capucina v. mesolepta Rabh.	M and T, IV, 1970: 130, pl. 1/7	Alk
constricta Ehr.	P and R, 1966: 122, pl. 3/17	Ac
construens (Ehr.) Grun.	M and T, VI, 1970: 131, pl. 1/11a-b	Alk
construens v. binodis (Ehr.) Grun.	M and T, VI, 1970: 131, pl. 1/12a-c	Alk
construens v. exigua (W. Sm.) Schulz	M and T, VI, 1970: 131, pl. 1/13	Alk
construens v. venter (Ehr.) Grun.	M and T, VI, 1970: 132, pl. 1/16-18	Alk
intermedia Grun.	M and T, VI, 1970: 133, pl. 11/22-23	Alk
lapponica Grun.	M and T, VI, 1970: 133, pl. 11/24a-c	C
lata (Cleve-Euler) Renberg	R, 1977: 316-318	Ac
leptostauron (Ehr.) Hust.	P and R, 1966: 124, pl. 4/2	Alk
pinnata Ehr.	M and T, VI, 1970: 133, pl. 11/27a-c	Alk
pinnata v. trigona (Brun, and Herib.) Hust.	P and R, 1966: 128, pl. 4/13	Alk**
vaucheriae (Kütz.) Peters	P and R, 1966: 120, pl. 3/14-15	Alk**
virescens Ralfs	M and T, VI, 1970: 134, pl. 11/35a-c	C
Frustulia		
rhomboides (Ehr.) DeT.	P and R, 1966: 306, pl. 21/5	Ac

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Species	Reference	pH
rhomboides v. amphipleuroides (Grun.) Cl.	P and R, 1966: 306, pl. 21/4	Ac
rhomboides v. capitata (A. Mayer) Hust.	P and R, 1966: 307, pl. 21/8	Ac
rhomboides v. saxonica (Rabh.) Det	P and R, 1966: 308, pl. 21/7	Ac
vulgaris Thwaites	P and R, 1966: 309, pl. 22/3	Ac
Gomphonema		
acuminatum Ehr.	P and R, 1972: 112, pl. 15/2,4,7	Alk
affine Kütz.	P and R, 1972: 133, pl. 17/5	Alk
gracile Ehr.	P and R, 1972: 131, pl. 17/1-3	Alk
intricatum Kütz.	P and R, 1972: 134, pl. 18/1	Alk
intricatum v. vibrio (Ehr.) Cl.	P and R, 1972: 135, pl. 18/4	Alk*
parvulum (Kütz.) Grun.	P and R, 1972: 122, pl. 17/7-12	Alk
subclavatum (Grun.) Grun.	P and R, 1972: 129, pl. 16/10	C**
subtile Ehr.	P and R, 1972: 117, pl. 16/1	Alk
truncatum Ehr.	P and R, 1972: 118, pl. 16/3	C*
truncatum v. capitatum (Ehr.) Patr. nom. nov.	P and R, 1972: 119, pl. 16/4	C**
truncatum v. turgidum (Ehr.) Patr. nom. nov.	P and R, 1972: 120, pl. 16/5	C**
sp 1		
Gyrosigma		
sp 1		Alk
Hantzschia		
amphioxys (Ehr.) Grun.	L, 1983: 166, pl. iv/1	Alk**

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Species	Reference	pH
Mastogloia		
grevillei W. Sm.	P and R, 1966: 298, pl. 20/8-9	
smithii v. lacustris Grun.	P and R, 1966: 299, pl. 20/12-13	Alk
Melosira		
ambigua O. Mull.	M and T, I, 1967: 203, pl. 1/1	Alk
arenaria Moore	M and T, I, 1967: 204, pl. 1/3	Ac
distans (Ehr.) Kütz.	H, 1930: 92, Fig. 53	Ac
granulata	H, 1930: 87, Fig. 44	Alk
islandica subsp. helvetica O. Mull.	M and T, I, 1967: 207, pl. i/9a-b	C**
italica (Ehr.) Kütz.	H, 1930: 91, Fig. 50	Alk
Italica subsp subarctica O. Mull.	M and T, I, 1967: 208, pl. i/12	Alk**
moniliformis (Muller) Agardh	M and T, I, 1967: 209, pl. 11/15a-b	
Meridion		
circulare (Grev.) Ag.	P and R, 1966: 113, pl. 2/15	Alk
circulare v. constrictum (Ralfs.) V.H.	P and R, 1966: 114, pl. 2/16	Alk**
Navicula		
bacillum Ehr.	P and R, 1966: 494, pl. 47/4-5	C*
clementis Grun.	P and R, 1966: 521, pl. 49/22	Alk**
contenta Grun.	T, VII, 1979: 12, pl. iii/50	C
cocconeiformis Greg. ex Grev.	P and R, 1966: 451, pl. 41/5	C
cryptocephala Kütz.	P and R, 1966: 503, pl. 48/3	Alk**

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Species	Reference	pH
cuspidata (Kütz.) Kütz.	P and R, 1966: 464, pl. 43/9-10	Alk
elginensis (Greg.) Ralfs.	P and R, 1966: 524, pl. 50/3	C
gastrum (Ehr. Kütz.)	P and R, 1966: 518, pl. 49/14	C
gibbosa Hust.	P and R, 1966: 479, pl. 45/16	
hassiaca Krasske	T, VIII, 1979: 18, pl. iii/54a-b	Ac
minima Grun.	P and R, 1966: 488, pl. 46/17-18	Alk
monmouthiana-stodderi Yerm.	P and R, 1966: 475, pl. 45/8	C
oblonga (Kütz.) Kütz.	P and R, 1966: 534, pl. 51/6	Alk
peregrina (Ehr.) Kütz.	P and R, 1966: 533, pl. 51/5	Alk
placentula (Ehr.) Kütz.	P and R, 1966: 523, pl. 50/1	Alk*
pseudocutiformis Hust.	P and R, 1966: 451, pl. 41/4	C
pupula Kütz.	P and R, 1966: 495, pl. 47/7	C
pulula v. rectangularis (Greg.) Grun.	P and R, 1966: 497, pl. 47/12	C
radiosa Kütz.	P and R, 1966: 506, pl. 48/15	C
radiosa v. parva Wallace	P and R, 1966: 510, pl. 48/16	C
radiosa v. tenella (Bréb. ex Kütz.) Grun.	P and R, 1966, 510, pl. 48/17	C
reinhardtii (Grun.) Grun.	P and R, 1966: 517, pl. 49/12	Alk
rhynchocephala Kütz.	P and R, 1966: 505, pl. 48/6	C*
scutelloides W. Sm. ex Greg.	P and R, 1966: 450, pl. 41/3	Alk
seminulum Grun.	P and R, 1966: 489, pl. 46/19	C
sovereignae Hust.	P and R, 1966: 452, pl. 41/6	
subtilissima Cl.	T, VIII, 1979: 31, pl. ii/15	Ac
tuscula Ehr.	P and R, 1966: 539, pl. 52/7	Alk

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Species	Reference	pH
Neidium		
affine (Ehr.) Pfitz.	P and R, 1966: 390, pl. 35/2	Ac
affine v. amphirhynchus (Ehr.) Cl.	P and R, 1966: 391, pl. 35/3	Ac
affine v. longiceps (Greg.) Cl.	P and R, 1966: 393, pl. 35/4	Ac
bisulcatum (Lagerst) Cl.	P and R, 1966: 397, pl. 36/5	Ac
bisulcatum v. baicalense (Skv. Meyer) Reim.	P and R, 1966: 397, pl. 36/6	C
hercynicum f. subrostrutum Wallace	P and R, 1966: 399, pl. 36/11-12	Ac
hitchcockii (Ehr.) Cl.	P and R, 1966: 395, pl. 36/2	Ac
iridis (Ehr.) Cl.	P and R, 1966: 386, pl. 34/1	Ac
iridis v. amphigomphus (Ehr.) V.H.	P and R, 1966: 387, pl. 34/2	Ac**
ladogense v. densestriatum (Ostr.) Foged.	P and R, 1966: 406, pl. 37/7	Ac
productum (W. Sm.) Cl.	P and R, 1966: 389, pl. 35/1	C**
Nitzschia		
filiformis (W. Sm.) Hust.	H, 1930: 422, Fig. 818	C
fonticola Grun.	H, 1930: 415, Fig. 800	Alk
gracilis Hantzsch	H, 1930: 416, Fig. 794	Alk
palea (Kütz.) W. Sm.	H, 1930: 416, Fig. 801	Alk
recta Hantzsch	H, 1930: 411, Fig. 785	Alk
sigmoidea Hust.	H, 1930: 419, Fig. 810	Alk
Peronia		
fibula (Bréb. ex Kütz.) Ross	P and R, 1966: 233, pl. 14/13	C
Pinnularia		
abaujensis (Pant.) Ross	P and R, 1966: 612, pl. 58/1-2	Ac

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Species	Reference	pH
abaujensis v. linearis (Hust.) Patr.	P and R, 1966: 613, pl. 58/3	Ac*
abaujensis v. subundulata (A. Mayer ex Hust.) Patr.	P and R, 1966: 614, pl. 58/4	Ac*
acrosphaeria v. turgidula Grun. ex Cl.	P and R, 1966: 624, pl. 60/4	C*
biceps Greg.	P and R, 1966: 599, pl. 55/14-15	C
braunii (Grun.) Cl.	P and R, 1966: 594, pl. 55/3	Ac
braunii v. amphicephala (A. Mayer) Hust.	P and R, 1966: 594, pl. 55/4	C
brebissonii (Kütz.) Rabh.	P and R, 1966: 614, pl. 58/6	Ac
dactylus Ehr.	P and R, 1966: 632, pl. 62/4	Ac
flexuosa Cl.	P and R, 1966: 637, pl. 63/7	Ac**
hilseana Jan.	L, 1983: 166: pl, iv/2-8	Ac
intermedia (Lagerst.) Cl.	P and R, 1966: 617, pl. 58/10	C
maior (Kütz.) Rabh.	P and R, 1966: 629, pl. 61/4	C
maior v. transversa (A. S.) Cl.	P and R, 1966: 630, pl. 61/6	Ac
mesolepta (Ehr.) W. Sm.	P and R, 1966: 600, pl. 55/17-18	Ac
mesolepta v. angusta Cl.	P and R, 1966: 601, pl. 55/19	C
microstauron Ehr. Cl.	P and R, 1966: 597, pl. 55/12	C
nodosa Ehr.	P and R, 1966: 601, pl. 55/20-21	C
parvula (Ralfs.) Cl. Eul.	P and R, 1966: 625, pl. 60/6	Ac**
rupestris Hantz	P and R, 1966: 630, pl. 61/7	Ac
subcapitata v. paucistraita (Grun.) Cl.	P and R, 1966: 597, pl. 55/11	Ac

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Species	Reference	pH
substomatatophora Hust.	P and R, 1966: 601, pl. 57/6	Ac*
sudetica Hilse	P and R, 1966: 611, pl. 57/9	Ac
undulata Greg.	H, 1930: 315, Fig. 565	C
viridis (Nitz.) Ehr.	P and R, 1966: 639, pl. 64/5	Ac
viridis v. communata	P and R, 1966: 640, pl. 64/6	Alkb*
Rhopalodia		
gibba (Ehr.) O. Mull.	P and R, 1972: 189, pl. 28/1	Alk
Semiorbis		
hemicyclus (Ehr.) Patr.	P and R, 1966: 163, pl. 9/7	Ab
Stauroneis		
anceps Ehr.	P and R, 1966: 361, pl. 30/1	C
anceps f. gracilis Rabh.	P and R, 1966: 361, pl. 30/2	C
phoenicenteron (Nitz.) Ehr.	P and R, 1966: 359, pl. 29/1-2	C
phoenicenteron f. gracilis (Ehr.) Hust.	P and R, 1966: 359, pl. 29/3-4	C
smithii Grun.	P and R, 1966: 365, pl. 30/12	C
staurolineata Reim.	P and R, 1966: 368, pl. 31/6	
sp		
Stenopterbia		
intermedia Lewis	T, XI, 1980: 28, pl. xix/246-247	Ac
intermedia f. capitata Fontell	T, XI, 1980: 28, pl. xix/248-249	Ac
Stephanodiscus		
astraea (Ehr.) Grun.	H, 1930: 110, Fig. 85	Alkb

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Species	Reference	pH
Surirella		
delicatissima Lewis	T, XI, 1980: 24, pl. xiv/210	C
linearis W. Sm.	H, 1930: 434, Fig. 837-838	Ac
linearis v. *constricta* (Ehr.) Grun.	H, 1930: 434, Fig. 839	
robusta Ehr.	H, 1930: 437, Fig. 850	
Synedra		
amphicephala Kütz.	H, 1930: 156, Fig. 173	
delicatissima W. Sm.	P and R, 1966: 136, pl. 5/2	Alk
parasitica (W. Sm.) Hust.	P and R, 1966: 140, pl. 5/12	Alk**
rumpens Kütz.	H, 1930: 156, Fig. 175	Ac
ulna (Nitz.) Ehr.	P and R, 1966: 148, pl. 7/1-2	Alk**
Tabellaria		
binalis (Ehr.) Grun.	P and R, 1966: 103, pl. 1/6	Ab
fenestrata (Lyngb.) Kütz.	P and R, 1966: 103, pl. 1/1-2	Ac
flocculosa (Roth) Kütz	P and R, 1966: 104, pl. 1/4-5	Ac
quadriseptata Kunds	P and R, 1966: 105, pl. 1/3	Ab